Appendix B:

Cornell-Dubilier Electronics, Inc. Superfund Site – Capacitor Disposal Area Summary

DRAFT FINAL

Technical Memo

Date: April 03, 2007

To: USACE-KCD

From: Malcolm Pirnie

Re: Cornell-Dubilier Electronics, Inc. Superfund Site – Capacitor Disposal Area Summary

1. Background

The purpose of this memo is to summarize the findings related to the "Capacitor Disposal Area" as discussed in the Remedial Investigation (RI) performed by Foster Wheeler Corporation, and Feasibility Study (FS) performed by Tetra Tech FW, Inc. Malcolm Pirnie will be assisting USACE-KCD in development of an interim remedial design for the excavation and off-site disposal of hazardous materials within the Capacitor Disposal Area. An understanding of the estimated limits and types of contamination as determined through the previous investigations will be required to perform the design.

2. Remedial Investigation Summary

According to the Remedial Investigation, the central undeveloped portion of the facility is primarily an open field (See attached Figure 4-10 of RI), with some wooded areas to the northeast and south, and a deteriorated, partially paved area in the middle. Historical activities on this property may have included the filling and disposal of equipment (i.e., capacitors and other electronic hardware), occasional spills/releases of transformer oils containing PCBs, and burning of waste oils and equipment contaminated with PCBs, as well as the potential burning of spent solvents and oils on site.

A geophysical survey of this portion of the property indicated the presence of anomalies, especially from the northeastern portion of the former truck driving school (fenced area) to the embankment leading to the Bound Brook. Test pits were excavated within the anomalous areas. Test Pit Records from TP-6, TP-8, TP-9, and TP-10 found evidence of various electrical components including electrical boxes thought to be capacitors, white and blue crystalline powder, and other miscellaneous electrical components. Subsurface samples also indicated that significant elevated Total PCB concentrations were present at these test pits. See attached RI Figure 4-3 for test pit locations and areas of geophysical survey anomalies. RI Test Pit Record logs for TP-6, TP-8, TP-9, and TP-10 are also attached.

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3. Feasibility Study Summary

Based on the test pit and geophysical survey findings of the RI, three sub-areas of the Capacitor Disposal Area were further defined in the FS. Attached Figure 4-5 of the FS shows the overall Capacitor Disposal Area and defines the limits of these three sub-areas.

1) **Capacitor Area 1-** Sub-Area 1 is located at the eastern corner of the central undeveloped portion of the site. Following the discovery of capacitors during the excavation of test pits TP-08 and TP-09, further inspection was performed by EPA and Tetra Tech personnel during the Remedial Investigation revealing that boxes appeared corroded and/or partially burned at these test pits. Other indications of disposal in these areas included the presence of white and blue crystalline powder, “mica-like” and “battery-shaped” pieces of material, 2-inch long white cylindrical objects, 5-inch diameter cardboard disks, and ceramic electrical components in TP-8 and TP-09. In addition, extremely elevated Total PCB concentrations are present in the subsurface soils at these test pits at less than 6 feet bgs (8,300 mg/kg in TP-08 and 29,000 mg/kg in TP-09). Based on these findings, this capacitor area was estimated at approximately 31,600 square feet in area and approximately 4 feet in depth, corresponding to total volume of approximately 126,400 cubic feet or 4,680 cubic yards.

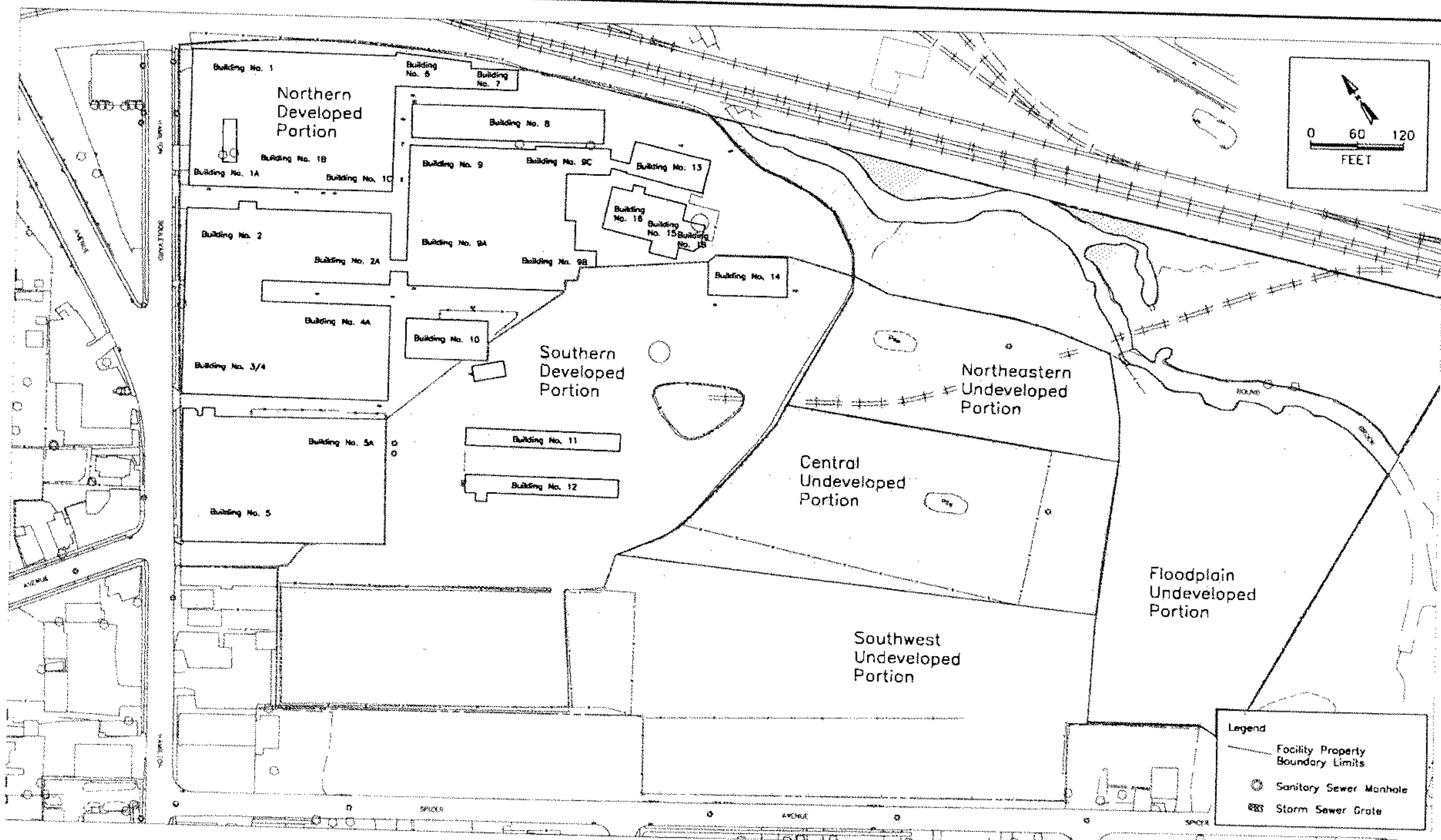
2) **Capacitor Area 2 –** Sub-Area 2 is located at the western corner of the central undeveloped portion. Capacitors were unearthed during the excavation of test pit TP-06. The Total PCBs in the TP-06 subsurface soil sample (less than 8 feet bgs) reached 6,600 mg/kg. Test pit TP-10 at its eastern boundary also contained white and blue crystalline power in the soil. This capacitor area was estimated at approximately 4,760 square feet in area and 5 feet in depth, corresponding to total volume of approximately 23,800 cubic feet or 880 cubic yards.

3) **Capacitor Area 3 –** Sub-Area 3 is located in the middle of the central undeveloped portion next to the Capacitor Area 1. This area was defined based only on geophysical survey anomalies and may potentially contain buried capacitor debris. The area was estimated at approximately 14,780 square feet in area and an assumed 4 feet in depth, corresponding to total volume of approximate 55,120 cubic feet or 2,040 cubic yards.

Remedial action objectives were identified and technologies were screened during the FS. Under alternatives S-2 through S-5, excavation and off-site disposal of the approximately 7,500 cubic yards within the Capacitor Disposal Areas were recommended.

4. Selected Remedial Actions for Capacitor Areas under Remedial of Reaction

The ROD indicates that the selected remedy for the site soils includes a combination of alternatives S-3 and S-5. This selected remedy includes excavation of an estimated 7,500 cubic yards of contaminated soil and debris from the capacitor areas described above and transportation for disposal off site, with treatment as necessary. Although the Capacitor Disposal Area poses a principal threat, treatment of all of the excavated debris was not considered because of the nature of the waste, which is primarily debris, and not amenable to treatment by low temperature thermal desorption, the selected technology for treatment of site soils. The soil and debris from the Capacitor Disposal Area, with PCB concentrations greater than 50 ppm would be transported to a TSCA landfill.

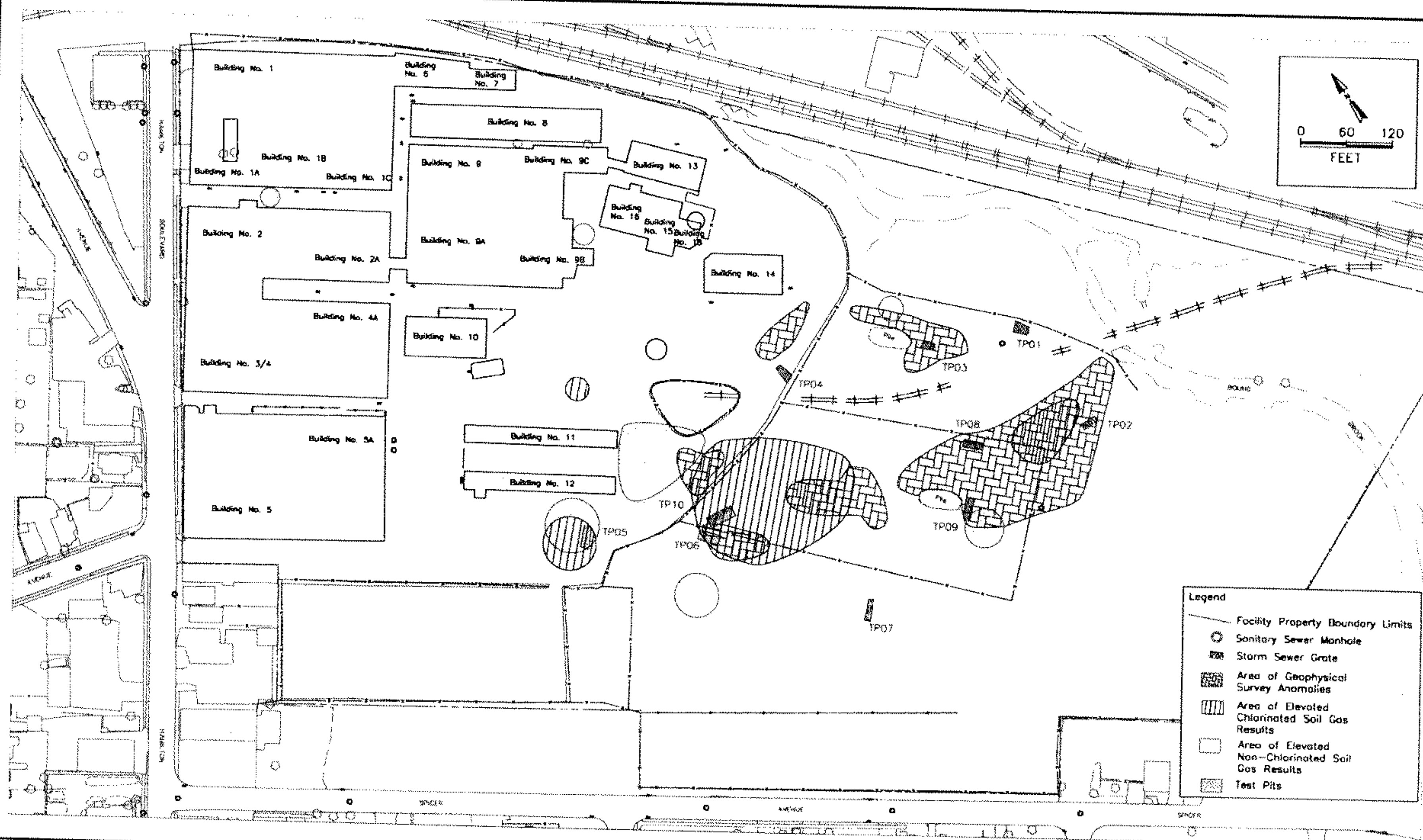


FOSTER WHEELER ENVIRONMENTAL CORPORATION

TITLE:
General Divided Facility Property Soil Areas
Cornell-Dubilier Electronics Superfund Site
Facility Soils and Buildings RI Report

DWN.: CTS	DATE: 05/10/01	PROJECT NO.: 1945.1018
CHKD: JG	REV.: 0	
DES.: LEN	APPD: LH	FIGURE NO.: 4-10

→ RI Fig. 4-10



FOSTER WHEELER ENVIRONMENTAL CORPORATION

TITLE:	DWN.:	DATE:	PROJECT NO.:
Possible Source Areas from OU-2 RI Investigation Cornell-Dubilier Electronics Superfund Site Facility Soils and Buildings RI Report	CTS	05/09/01	1945.1018
	CHKD.: JG	REV.: 0	
	DES.: LEN	APPD: LH	FIGURE NO.: 4-3

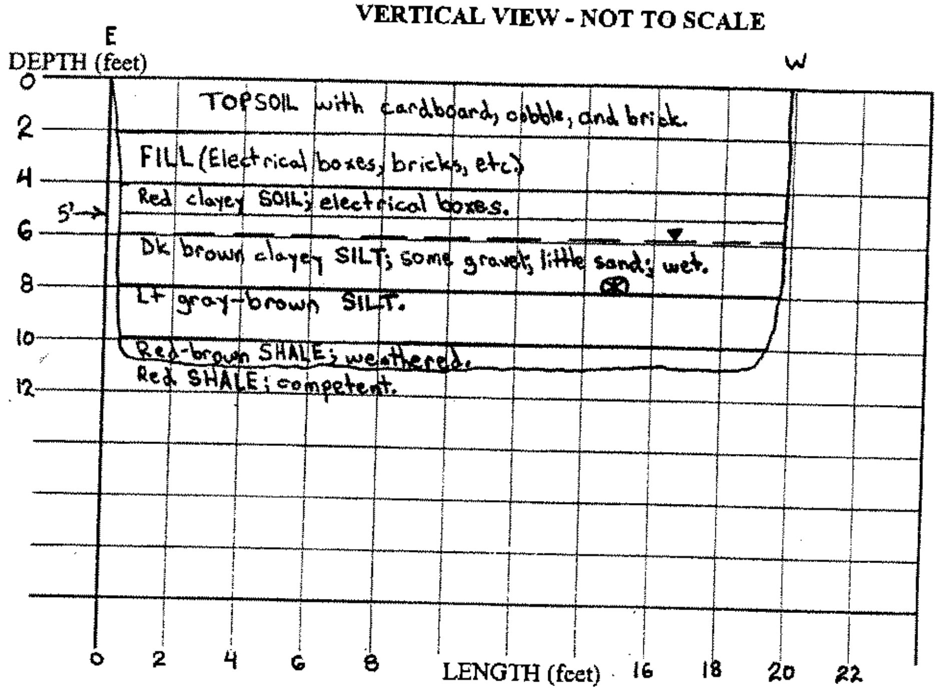
→ RI Fig. 4-3

TP-06

TEST PIT RECORD

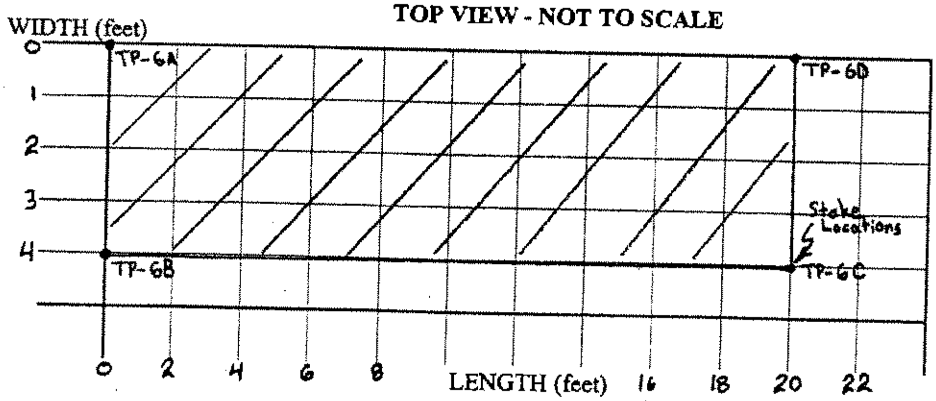
PROJECT: Cornell-Dubilier Electronics Superfund	TEST PIT NUMBER: TP06
PROJECT NO: 1945.1018.0300	DATE STARTED: 06/12/00
LOCATION: West/southwest of truck driving school area.	DATE COMPLETED: 06/12/00
GEOLOGIST: T. Fowler	GROUNDWATER DEPTH: ~ 6 ft bgs
EXCAVATION COMPANY: Tabasco Drilling	Wet @~3 ft bgs

VERTICAL VIEW - NOT TO SCALE



Air Monitoring
Air monitoring with the PID
and FID measured 0 ppm in
test pit soils and breathing
zone, except:
FID = 26.9 ppm at 1507 in
test pit soils.
FID = 10.3 ppm at 1542 in
test pit soils.

TOP VIEW - NOT TO SCALE



NOTES: * Sample TP06-01 collected at approximately 7 to 8 ft bgs and 5 ft from the western edge. Groundwater sample TPW06-01 collected from test pit.

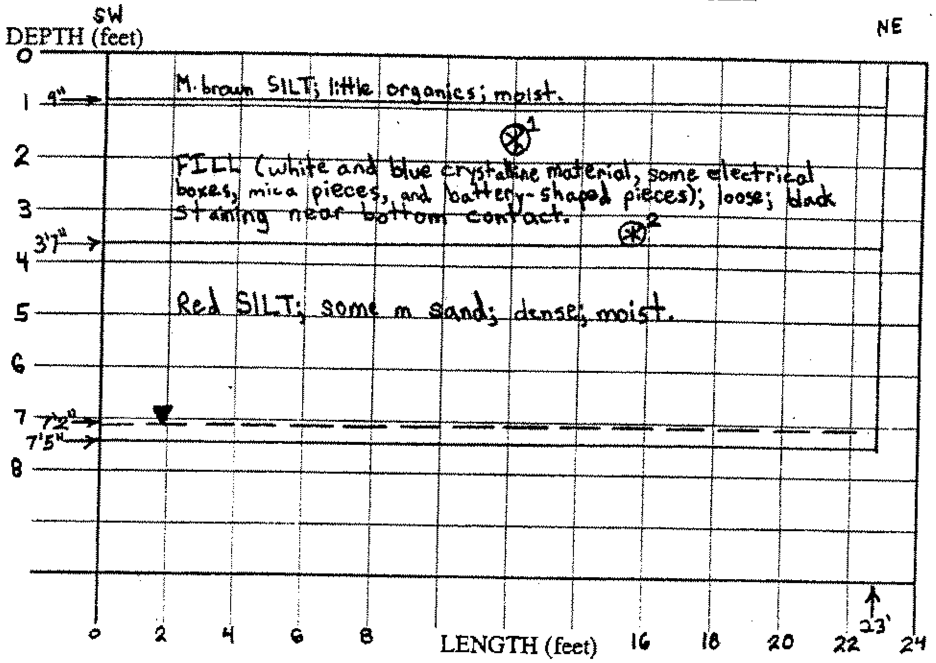
Legend:
PID: photo-ionization detector
FID: flame ionization detector
ppm: parts per million
ft: feet
bgs: below ground surface

TP-08

TEST PIT RECORD

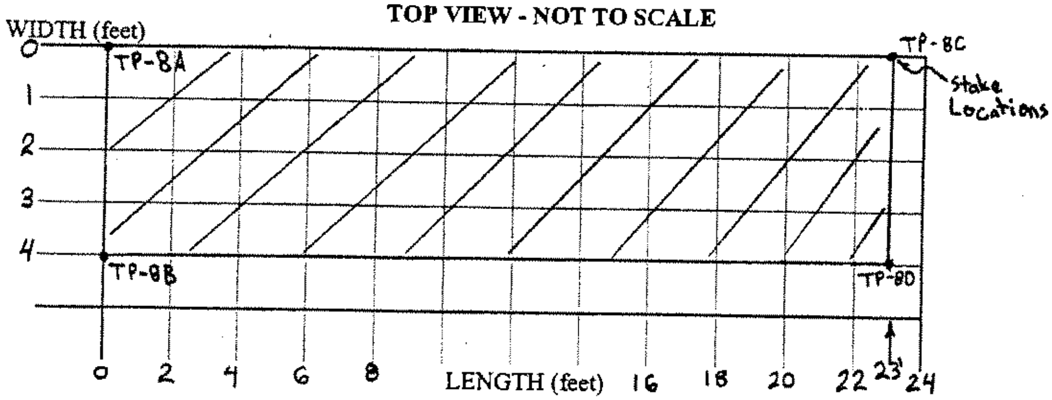
PROJECT:	Cornell-Dubilier Electronics Superfund	TEST PIT NUMBER:	TP08
PROJECT NO:	1945.1018.0300	DATE STARTED:	06/09/00
LOCATION:	South of fence inside truck school area.	DATE COMPLETED:	06/09/00
GEOLOGIST:	M. Greenberg	GROUNDWATER DEPTH:	7.2 ft bgs
EXCAVATION COMPANY:	Tabasco Drilling		

VERTICAL VIEW - NOT TO SCALE



Air Monitoring
Air monitoring with the PID and FID measured 0 ppm in test pit soils and breathing zone.
Dust monitoring with the mini-ram measured 0.0.

TOP VIEW - NOT TO SCALE



NOTES: *1 Sample TP08-01 collected at 1.5 ft bgs and 11 ft from northeast edge.
*2 Sample TP08-02 collected at 3.5 ft bgs and 7.5 ft from northeast edge.
Groundwater sample TPW08-01 collected from test pit.

Legend:
PID: photo-ionization detector
FID: flame ionization detector
ppm: parts per million
ft: feet
bgs: below ground surface

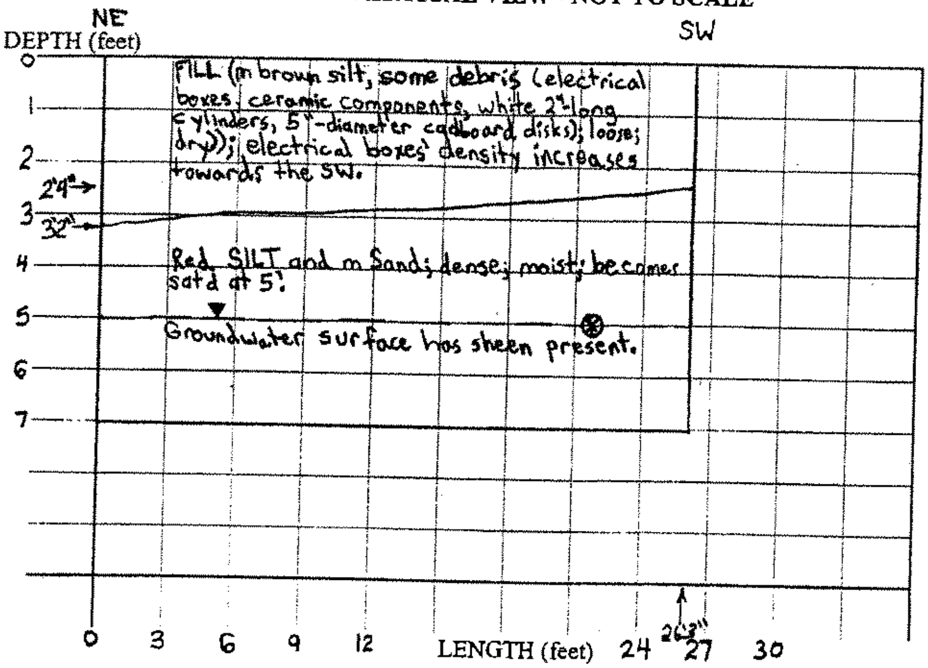
TP-09

TEST PIT RECORD

PROJECT: Cornell-Dubilier Electronics Superfund
PROJECT NO: 1945.1018.0300
LOCATION: West of eastern fence in truck school area.
GEOLOGIST: M. Greenberg
EXCAVATION COMPANY: Tabasco Drilling

TEST PIT NUMBER: TP09
DATE STARTED: 06/09/00
DATE COMPLETED: 06/09/00
GROUNDWATER DEPTH: 5 ft bgs

VERTICAL VIEW - NOT TO SCALE



Air Monitoring

Air monitoring with the PID and FID measured 0 ppm in the test pit soils and breathing zone, except, in test pit soils:

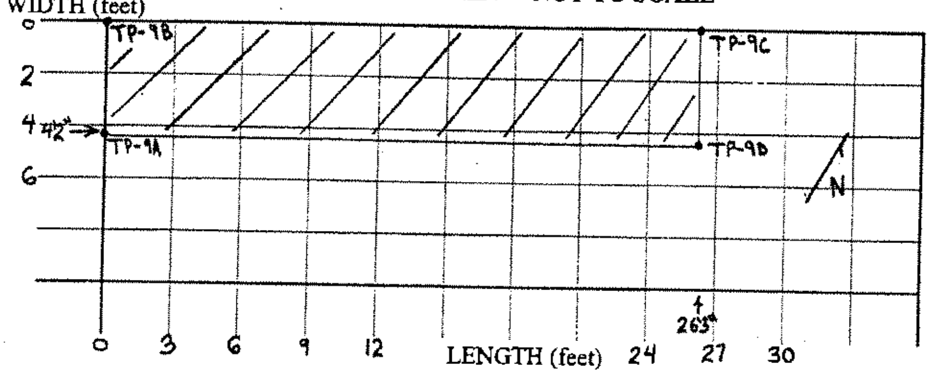
FID = 2.2 ppm at 1319.
FID = 13.3 ppm at 1403.
FID = 16.4 ppm at 1412.

In breathing zone:

FID = 2 ppm at 1403.

Dust monitoring with the miniram measured 0.

TOP VIEW - NOT TO SCALE



NOTES: * Sample TP09-01 collected at 5 ft bgs and 22 ft from the northeast edge.
Groundwater sample TPW09-01 and duplicate, TPW99-01, collected from test pit.

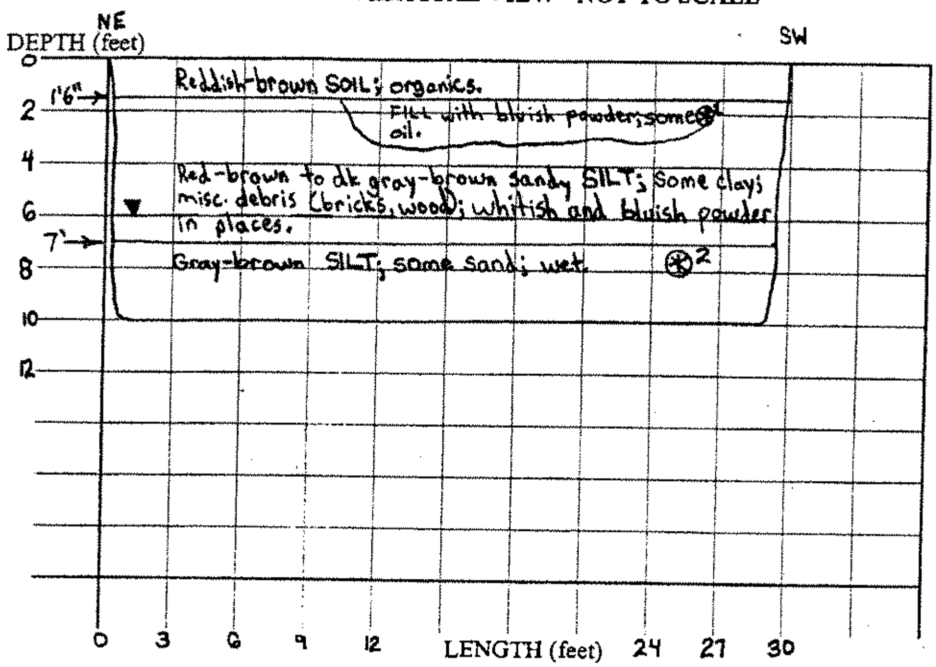
Legend:
PID: photo-ionization detector
FID: flame ionization detector
ppm: parts per million
ft: feet
bgs: below ground surface

TP-10

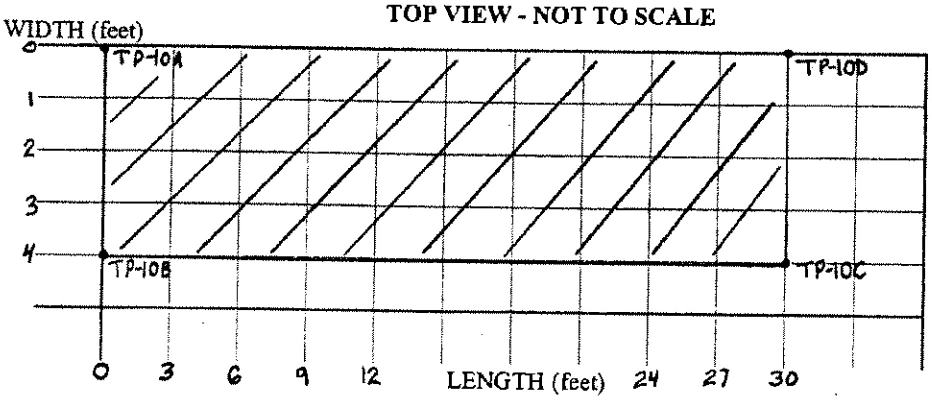
TEST PIT RECORD

PROJECT: Cornell-Dubilier Electronics Superfund	TEST PIT NUMBER: TP10
PROJECT NO: 1945.1018.0300	DATE STARTED: 06/12/00
LOCATION: West/southwest area of truck driving school.	DATE COMPLETED: 06/12/00
GEOLOGIST: T. Fowler	GROUNDWATER DEPTH: ~ 6 ft bgs
EXCAVATION COMPANY: Tabasco Drilling	

VERTICAL VIEW - NOT TO SCALE



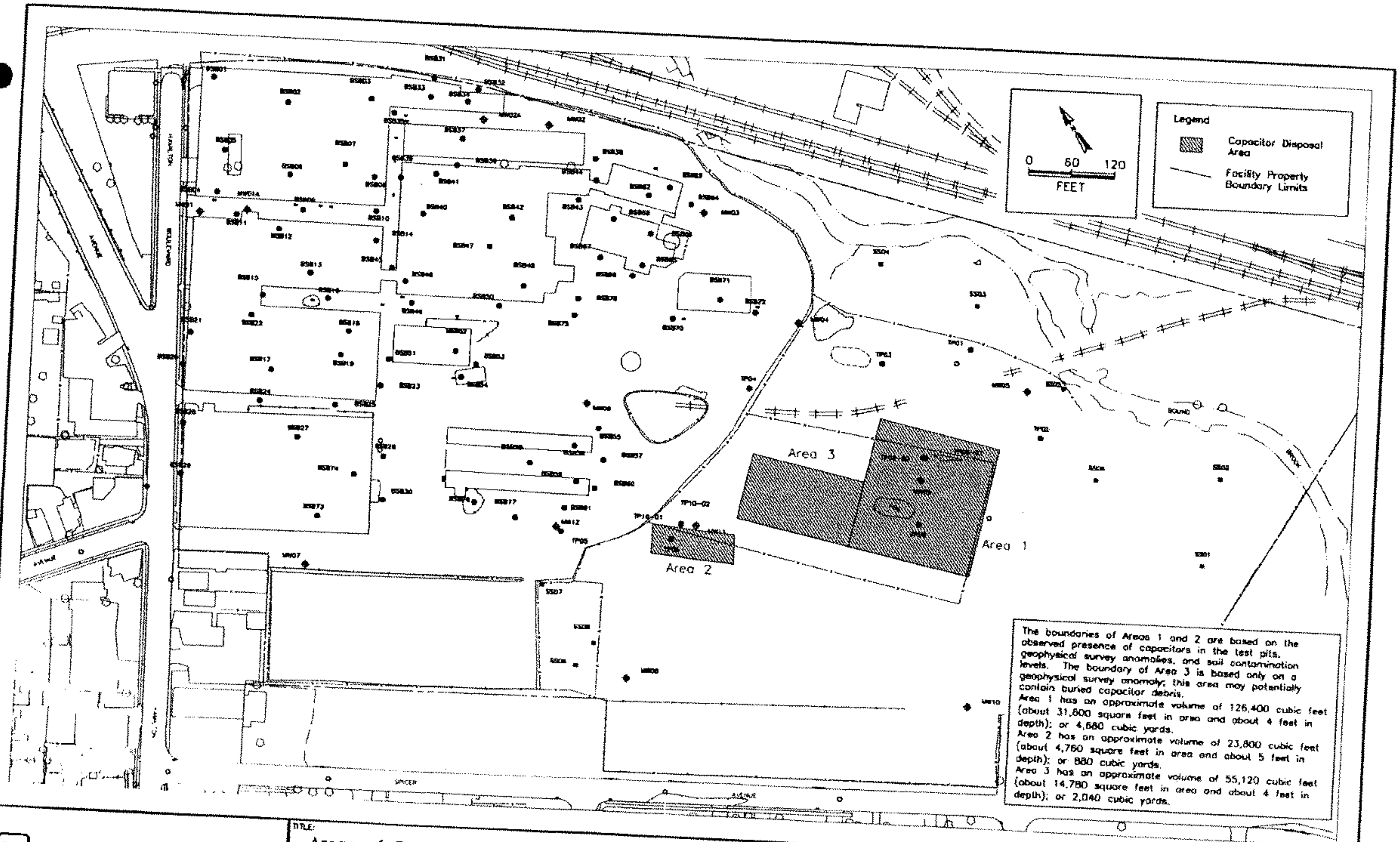
TOP VIEW - NOT TO SCALE



Air Monitoring
Air monitoring with the
PID and FID measured 0 ppm
in test pit soils and breathing
zone except in test pit soils:
FID = 13.3 ppm, PID=7.6 ppm
at 0919.
FID=24.4 ppm, PID=10.7 ppm
at 0936.
FID=3.8 ppm, PID=8.3 ppm
at 1008.
FID = 83.4 ppm at 1020.
FID = 2 ppm at 1032.
FID = 24 ppm at 1037.
FID=8.7 ppm, PID=10.7 ppm
at 1042.
Dust monitoring with the mini-
ram measured 0.0.

NOTES:
*[1] Sample TP10-01 collected at approximately 2 ft bgs and 5 ft from southwest edge.
*[2] Sample TP10-02 collected at approximately 8 ft bgs and 6 ft from southwest edge.
Groundwater sample TPW10-01 collected from test pit.

Legend:
PID: photo-ionization detector
FID: flame ionization detector
ppm: parts per million
ft: feet
bgs: below ground surface



TETRA TECH FW, INC.	TITLE: Areas of Potentially Buried Capacitor Debris Cornell-Dubilier Electronics Superfund Site Facility Soils and Buildings FS Report	DWN: LEN CHKD: BMS	DATE: 03/29/04 REV: 1	PROJECT NO: 1945.2118 FIGURE NO: 4-5

→ FS Fig. 4-5

Appendix C:

Bound Brook Watershed Hydraulics and Sediment Impact Analyses Modeling

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Table of Contents

1. Introduction

1.1. Purpose

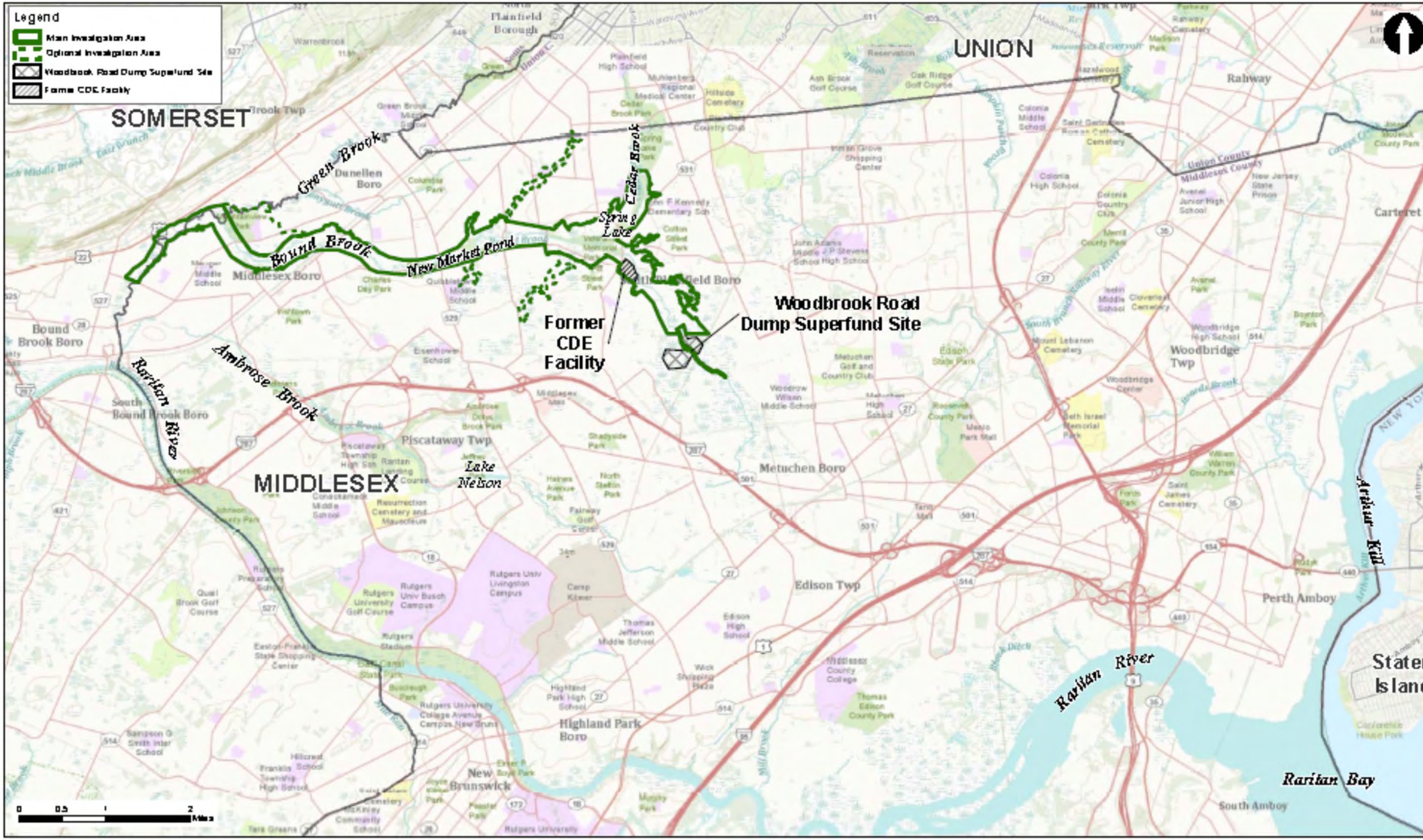
The Bound Brook hydraulic and sediment impact modeling analyses are one of the decision making tools used to evaluate potential remedial alternatives for reducing ecological and human health risks posed by contaminated sediments in Bound Brook, New Jersey. Bound Brook, located in Middlesex County, New Jersey, is a secondary tributary of the Raritan River that flows into Raritan Bay (south of Staten Island, New York) and into the Greater New York/New Jersey Harbor (Figure 1-1). Bound Brook is part of Operable Unit (OU) 4 of the Cornell-Dubilier Electronics (CDE) Superfund Site (Site) [EPA ID: NJD981557879] located in South Plainfield, New Jersey. Cornell-Dubilier Electronics, Inc. operated a facility at 333 Hamilton Boulevard from 1936 to 1962, manufacturing electronic parts and components including capacitors. During site operations, the company released/buried material contaminated with polychlorinated biphenyls (PCBs) and chlorinated volatile organic compounds (CVOCs), primarily trichloroethene (TCE), contaminating on-site soils. As part of the ongoing RI/FS process for OU4 (Section 1.0 of the Draft Final Focused Feasibility Report, 2014), USEPA has detected elevated levels of PCBs and CVOCs in the surface water and sediments of Bound Brook adjacent to the former CDE facility's northeast property line.

The objective of this Bound Brook modeling effort is to use established models that adequately represented the processes affecting stream hydraulics, sediment supply, and sediment transport, especially since hydrophobic contaminants, like PCBs, are preferentially transported in the particulate phase and sorbed to fine-grained sediments. The model simulated results were used to assess the relative impacts of stream flow and sediment transport in Bound Brook under various remediation scenarios.

1.2. Modeling Approach

The hydraulics and sediment impact modeling analyses were conducted for Bound Brook from immediately downstream of Belmont Avenue Bridge (RM6.87) to its confluence with Green Brook (RM0) (Figure 1-2). The modeling framework developed for the Bound Brook RI/FS consisted of:

- <u>A watershed model that provided inputs of runoff and sediments into the in-stream hydraulics and sediment analyses model</u>. The hydrologic model Soil Water Assessment Tool [SWAT; (Arnold *et. al.,* 1998)] Version 2009 was selected to perform the simulation of continuous water movements and sediment yield through various types of land uses in the watershed. Please note that SWAT is a continuous-time simulation, semi-distributed, quasi-process-based watershed model and the ArcSWAT interface was used to prepare the inputs into the SWAT model.

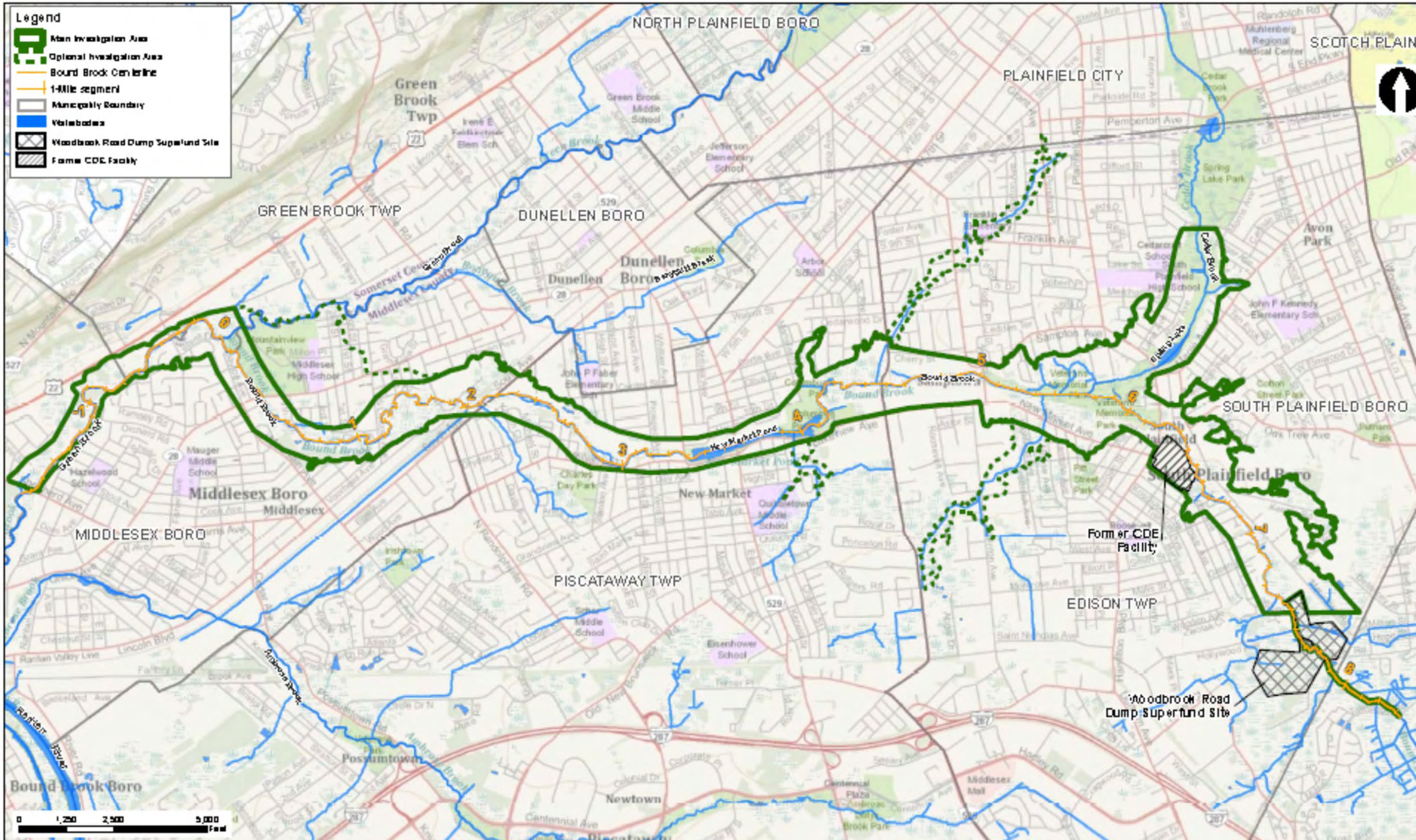


Cornell-Dubilier Electronics
Superfund Site
South Plainfield, New Jersey

OU4 Bound Brook Regional Location Map

2013

Figure 1-1



	Cornell-Dubilier Electronics Superfund Site South Plainfield, New Jersey	**OU 4 Bound Brook Study Area** *Bound Brook OU4 RI/FS*	2013 Figure 1-2

- An in-stream hydraulic and sediment impact analysis model was prepared using the Hydrologic Engineering Center-River Analysis System (HEC-RAS) as part of this component of the modeling framework. The HEC-RAS is a one-dimensional and physically-based modeling system to analyze river flow, sediment, and water quality dynamics. HEC-RAS was selected because it has been present in the public realm for more than 15 years and has been peer reviewed (USACE, 2010a,b). It is freely available for download from the HEC website and is supported by the US Army Corps of Engineers. It is also widely used by many government agencies and private firms. The SWAT model and HEC-RAS were externally coupled[1], such that the results of the SWAT model were used as an input to the HEC-RAS model without changing the codes of the models.
- A sediment assessment model was constructed within HEC-RAS, using the SIAM (Sediment Impact Assessment Model) feature. The SIAM tool was recommended by USACE for sediment assessment in this study because it is already part of the HEC-RAS modeling system.

[1] External coupling occurs when one program calls another program (executable file) explicitly, and there is a mechanism of external data exchange, either by a text file I/O or by more sophisticated inter-process communication (Yahiaoui *et. al.*, 2004).

2. Watershed Modeling

2.1. Watershed Study Area

The headwaters of Bound Brook originate in areas of residential and commercial/industrial development in Edison Township (see Figure 1-2). Bound Brook flows westerly through South Plainfield into Piscataway Township, where the water is dammed to form New Market Pond. The brook flows through Middlesex Borough to the confluence with Green Brook, a tributary of the Raritan River.

The Bound Brook watershed up to its confluence with Green Brook (Figure 1-2) is un-gauged. Consequently, the Green Brook watershed was included in the study to help with the calibration of Bound Brook flows, since the USGS gauge (Gauge ID: 01403900) is located immediately below the confluence of Bound Brook and Green Brook and provides the only measured/observed flow data with long-term flow measurements dating back to 1972. However, continuous flows were only measured in the period between 2004 and 2011. Figure 2.1 depicts the Bound Brook watershed area (approximately 27 square miles) and the Green Brook watershed area (area without black sub-basin polygons). Bound Brook has elevations ranging from 12 m to 59 m (NAVD88), while the elevation in the Bound Brook and Green Brook watershed ranges from 12 m to 172 m (NAVD88).

2.2. Watershed Modeling Methodology

The GIS interface for SWAT model (ArcSWAT) was used to develop the inputs for simulating the Bound Brook watershed flows and sediment. The ArcSWAT GIS Interface, Version 10.1 was used for model parameterization. Total years of study were from the period of 2004 to 2011, when continuous flow data were available from the above listed USGS gauge (Gauge ID: 01403900). The year 2004 was used as a warm-up period for the model while 2005 through 2007 was used for model calibration and 2008 through 2011 was used for model validation. This division of the entire 2005-2011 period into calibration and validation periods ensures that both periods have a similar number of wet and dry years.

SWAT-CUP version 4.3.7 (Abbaspour *et. al.*, 2007) was used for sensitivity analysis and model calibration. SWAT-CUP provides a decision making framework that incorporates a semi-automated approach (SUF12) using both manual and automated calibration and incorporates a sensitivity and uncertainty analysis. In SWAT-CUP, users can manually adjust parameters and ranges iteratively between autocalibration runs. Parameter sensitivity analysis helps focus the calibration and uncertainty analysis and is used to provide statistics for goodness-of-fit.

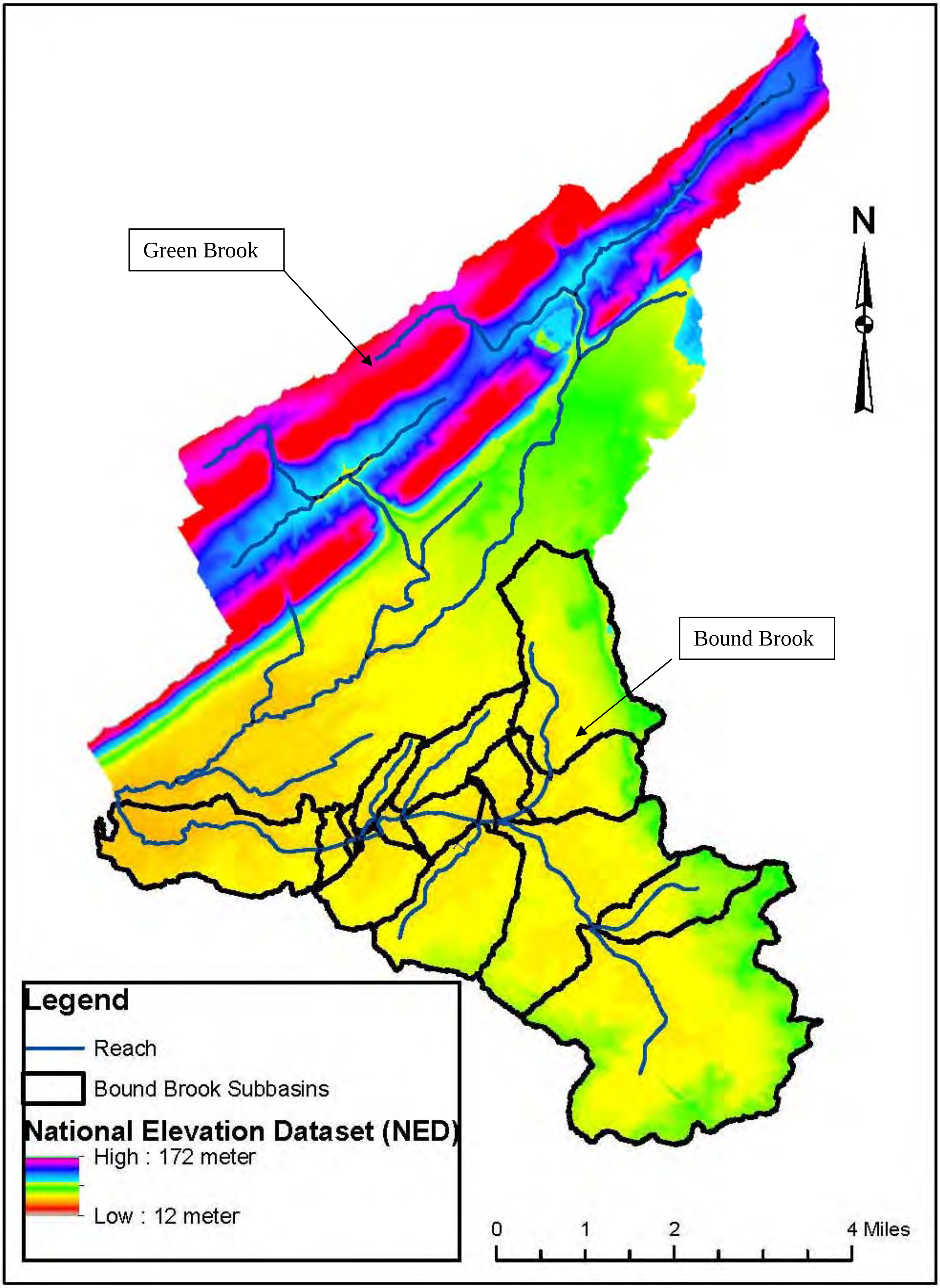


Figure 2.1: Bound Brook Watershed (marked in bold black line) and Green Brook Watershed

2.3. Principles of the SWAT Model

SWAT is a continuous-time simulation, semi-distributed, quasi-process-based watershed model. The model operates on a daily time step and was developed to evaluate the effects of alternative management decision on water resources and non-point-source pollution in ungauged watersheds. Major model components include weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management. The hydrologic components of SWAT are based on the water balance equation applied to water movement through soil. The water balance equation takes into account several different processes, including: precipitation, surface runoff, evapotranspiration, recharge, and soil water storage. The water balance is expressed in SWAT as follows:

$$SW_t = SW_0 + \sum_{i=1}^{t} \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw} \right) \qquad (1)$$

Where

SW_t = soil water content at time t (mm)
SW_0 = initial soil water content of day i (mm)
R_{day} = amount of precipitation on day i (mm)
Q_{surf} = amount of surface runoff on day i (mm)
E_a = amount of evapotranspiration on day i (mm)
W_{seep} = amount of water percolation to the bottom of the soil profile on day i (mm)
Q_{gw} = amount of water returning to the ground water on day i (mm)
t = time (in days)

The structure of the SWAT model can be summarized as follows:

- The SWAT model subdivides the watershed into several sub-watersheds, which are further divided into hydrological response units (HRUs) according to topography, land use, and soil. The number of HRUs in a sub-watershed is determined by the threshold value for land use and soil delineation in the sub-watershed (Neitsch *et. al.*, 2011). The delineation of the HRUs within the sub-watershed is determined using ArcSWAT built-in tools (Winchell *et. al.*, 2007). The use of HRUs generally simplifies a simulation run because all similar soil and land-use areas are lumped into a single response unit.
- The hydrologic cycle is climate driven and provides moisture and energy inputs, such as daily precipitation, maximum/minimum air temperature, solar radiation, wind speed, and relative humidity, that control the water balance. The water balance in each HRU is represented by four storage volumes: snow, soil profile (0-6.5 feet), shallow aquifer (typically 6.5-65 feet) and deep aquifer (> 65 feet). Snow is computed when temperatures are below freezing, and soil temperature is computed because it impacts water movement in the soil.
- As precipitation descends, it may be intercepted and held in the vegetation canopy or fall to the surface of the soil. Water on the soil surface will infiltrate into the soil profile or flow overland as surface runoff. Runoff moves relatively quickly towards a stream channel and contributes to short-term stream response. Infiltrated water may be held in the soil and later

evapotranspirated or it may slowly make its water to the surface-water system via underground paths. The potential pathways of water movement simulated by SWAT in the HRU are given in Figure 2.2.

- Surface runoff occurs whenever the rate of eater application to the ground surface exceeds the rate of infiltration. In this study, surface runoff from daily precipitation is estimated using the Soil Conservation Service (SCS) curve number (CN) method as implemented in SWAT.
- The soil profile is subdivided into multiple layers that may have differing soil-water processes including infiltration, evaporation, plant uptake, lateral flow, and percolation to lower layers. The soil percolation component of SWAT uses a storage routing technique to predict flow through each soil layer in the root zone. Downward flow occurs when field capacity (the water content to which a saturated soil drains under gravity) of a soil layer is exceeded and the layer below is not saturated. Percolation from the bottom of the soil profile recharges the shallow aquifer. When the temperature in a particular layer is equal to or below 48°F, no percolation is allowed from that layer. Lateral subsurface flow in the soil profile is calculated simultaneously with percolation, and this can contribute to stream flow.
- Water that moves past the lowest depth of the soil profile by percolation or bypass flow enters the vadose zone before becoming shallow and/or deep aquifer recharge. The shallow aquifer contributes base flow to the main channel or reaches within each subbasin. Base flow is allowed to enter the reach only when the amount of water stored in the shallow aquifer exceeds a threshold value. Water entering the deep aquifer is not considered in future water budget calculations and is considered to be lost from the system..
- SWAT uses the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1995) to predict sediment yield from the landscape. Sediment yield is the total sediment volume delivered to a specified location in the basin, divided by the effective drainage area above that location for a specified period of time.

$$sed = 11.8 \cdot \left(Q_{surf} \cdot q_{peak} \cdot area_{hru}\right)^{0.56} \cdot K \cdot C \cdot P \cdot LS \cdot CFRG \qquad (2)$$

where

sed = sediment yield on a given day (metric tons)
Q_{surf} = surface runoff volume (mm/ha)
Q_{peak} = peak runoff rate (m^3/s)
$area_{hru}$ = area of HRU (ha)
K = soil erodibility factor (0.013 metric ton m^2/hr/(m^3-metric ton cm))
C = cover and management factor
P = support practice factor
LS = topographic factor
$CFRG$ = coarse fragment factor

- Flows and sediment yield from each HRU in a subwatershed are combined, and the resulting flow and loads are routed through channels (Neitsch and others, 2005), ponds, and (or) reservoirs to the watershed outlet. In this study, channel flow is routed by Muskingum method, and channel sediment is routed based on the modified Bagnold's sediment transport equation.

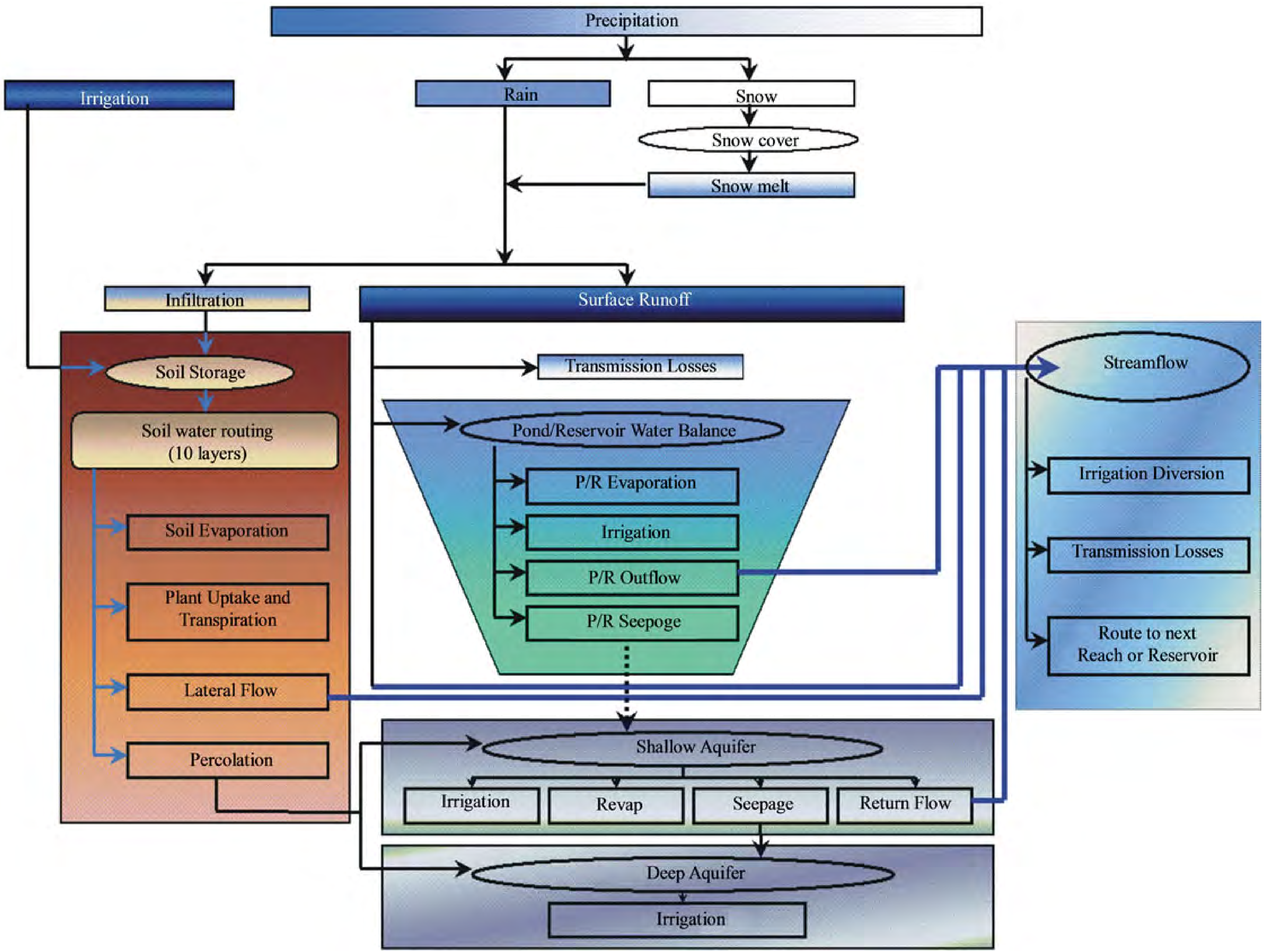


Figure 2.2: Schematic of pathway available for water movement in SWAT (after Neistch *et. al*, 2009)

2.4. Model Components and Input Data

The steps involved in creating and running SWAT model are given in Figure 2.3 below. The major model inputs are topography[2], soil properties (such as texture, soil erodibility, hydraulic conductivity, hydrologic soil group, soil depth, organic matter content, available water capacity), land use/cover type, weather/climate, and land management practices. Using the site topography, the SWAT ArcGIS interface delineates the stream and partitions the watershed into subwatersheds, which are positioned in the watershed and are related to one another spatially (*e.g.*, outflow from upstream sub-watershed number 3 may enter downstream subwatershed number 6). The subwatersheds are further processed and divided into the HRUs. SWAT then uses the input data from the user to create inputs files with different levels of detail for the watershed, subwatershed, or HRU. Watershed level inputs are used to model processes throughout the watershed, while subwatershed or HRU inputs files are used to identify unique processes to specific subwatershed or HRUs.

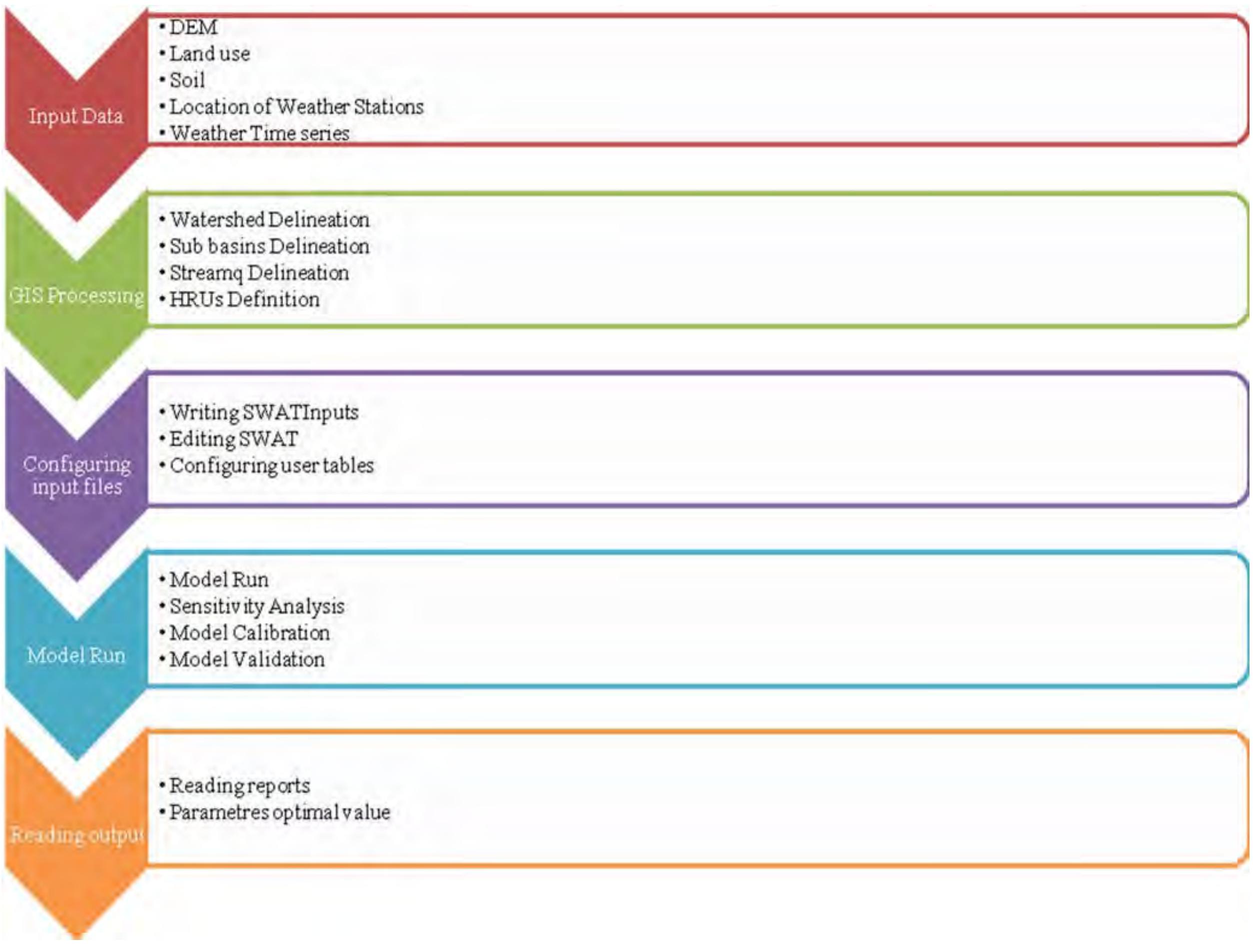


Figure 2.3 Components and input/output data of SWAT Model (after Kharchaf et al., 2013)

[2] The topography is represented by three-dimensional or a digital elevation model (DEM) in Figure 2.3

2.4.1. Watershed National Elevation Dataset (NED) and Watershed Delineation

The National Elevation Dataset (NED) 1/9 Arc Second assembled by the U.S. Geological Survey was used in representing the elevation terrain of the watershed. NED 1/9 Arc Second data are Light Detection and Ranging (LIDAR) data. Data unit is meters with a geographic projection. Data has a vertical datum of NAVD88 and a horizontal projection of NAD83. The resolution of the data is approximately 3 meters with a vertical accuracy of +/- 1 meter. For this modeling effort, NED data was re-projected to New Jersey State Plane Coordinate with metric units (meters). Approximate watershed elevation range between 12 meters to 172 meters with reference to NAVD88 (Figure 2.2).

Using the Automatic Delineator command in ArcSWAT, the re-projected NED topographic map in ESRI GIS format was imported to start the watershed delineation processes. Watershed delineation involves the use of advanced GIS functions to aid the user in segmenting the watershed into several hydrologically connected sub-watersheds for use in the SWAT. When the automated delineation was completed for Bound Brook watershed, it was observed that one of the tributaries that flow into Bound Brook was delineated to flow into Green Brook; inconsistent with the surface water quality shapefiles downloaded from the NJDEP website (http://www.state.nj.us/dep/gis/stateshp.html#SWQS). Therefore, manual adjustments were made to ArcSWAT's delineation to match the stream network in the NJDEP shapefiles. The stream network and the delineated sub-watershed that were finally used in the SWAT model are depicted in Figure 2.2.

2.4.2. Watershed Land Use Data

The USGS National Land Cover Database (NLCD) 2006 Land Cover data were used to represent the land use in the watershed. Data resolution is 1 arc second (approximately 30 meters). For consistency with the NED data described in Section 2.4.1, data was re-projected to New Jersey state plane coordinate with a horizontal datum of meter NAD83. There are 15 classes of land use types in the Bound Brook watershed (Figure 2.3). The percent area represented by each land use is listed in Table 2.1.

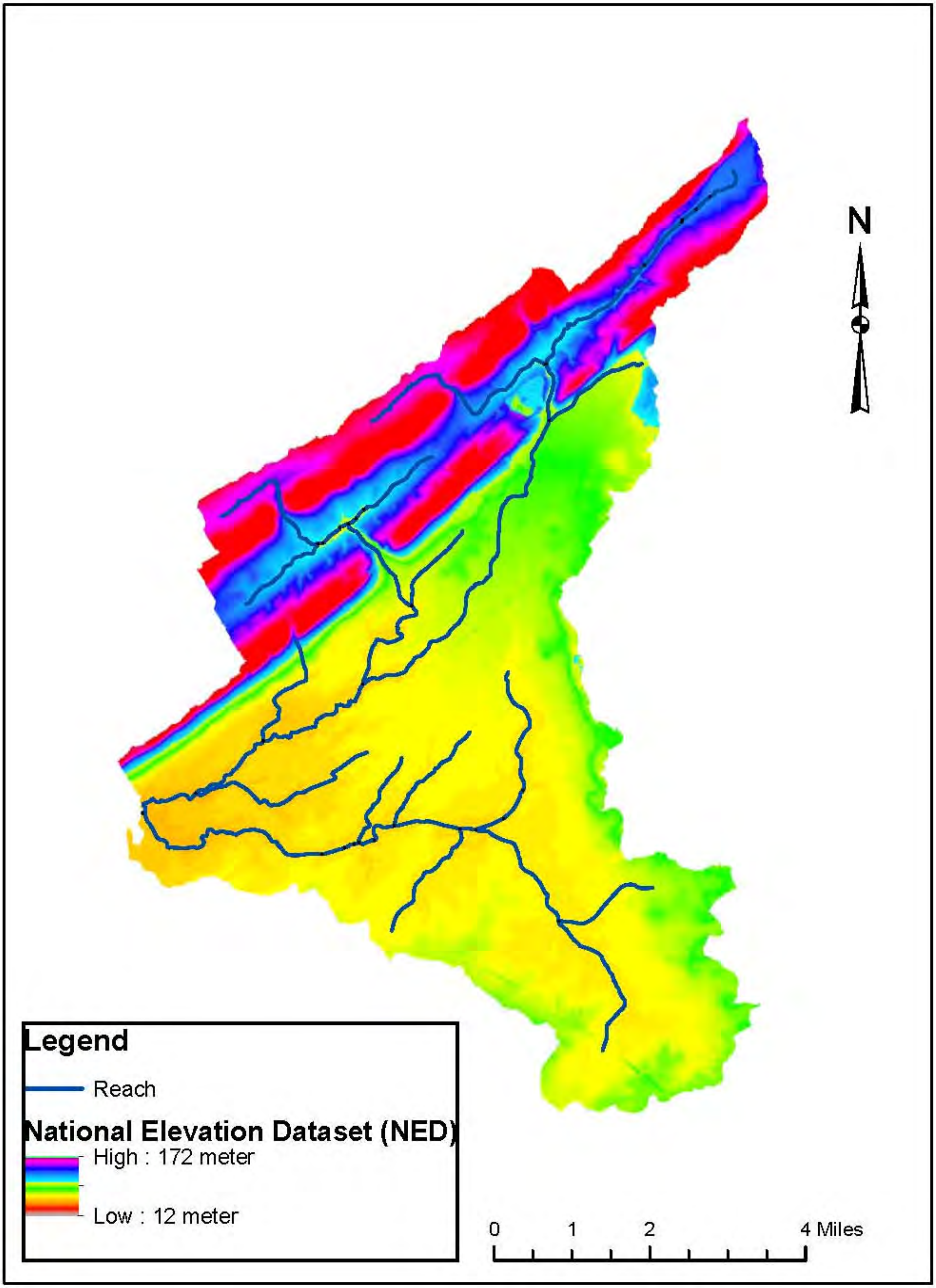


Figure 2.2: National Elevation Dataset for the Bound Brook and Green Brook Watersheds

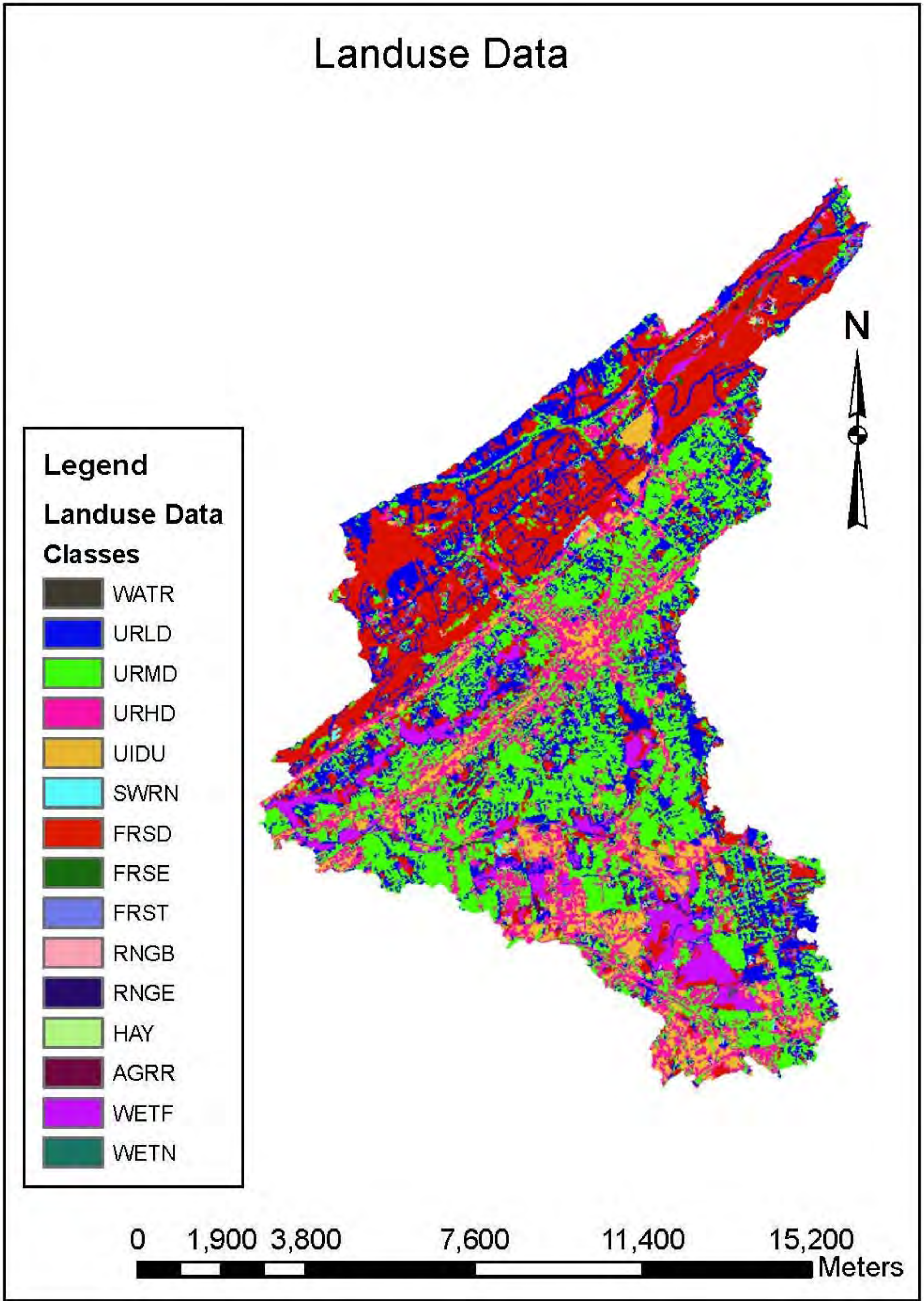


Figure 2.3: Watershed Land Use Classification for the Bound Brook and Green Brook Watersheds

Table 2.1: Land Use Percent Areas

Land Use	Area (%)
Water (WATR)	0.1%
Residential-Low Density (URLD)	21.3%
Residential-Medium Density (URMD)	30.1%
Residential-High Density URHD	13.2%
Industrial (UIDU)	5.4%
Range (SWRN)	0.2%
Forest-Deciduous (FRSD)	23.0%
Forest-Evergreen (FRSE)	0.1%
Forest (FRST)	1.0%
Range-Brush (RNGB)	0.4%
Range-Grasses (RNGE)	<0.1%
Hay (HAY)	<0.1%
Agricultural Land-Row Crops (AGRR)	0.1%
Wetlands-Forested (WETF)	5.0%
Wetlands-Non-Forested (WETN)	0.1%

2.4.3. Watershed Soil Data

The USGS Soil Survey Geographic (SSURGO) data were used in classifying the soil characteristics of the watershed. The SSURGO data consists of digital georeferenced spatial data, attribute data, and metadata. The SSURGO data provides the most detailed level of information and was designed primarily for farm and ranch, landowner/user, township, county, or parish natural resource planning and management. Using the soil attributes, these data serve as a resource for the determination of erodible areas, developing erosion control practices, making land use assessments and chemical fate assessments. For consistency with the NED and landuse data described in Sections 2.4.1 and 2.4.2, SSURGO data were re-projected to New Jersey state plane coordinates with a horizontal datum of meter NAD83. There are over 100 classes of soil in the Bound Brook watershed (Figure 2.4) and the percent area represented by each soil group is shown in Table 2.2.

2.4.4. Meteorological Data

Two precipitation weather stations namely, NOAA gauge in Plainfield NJ (Gauge ID: 287079) and NOAA gauge in Bound Brook, NJ (Gauge ID: 280927) were used to represent precipitation in the watershed. The Plainfield gauge was also used to represent temperature in the watershed. Relative humidity and wind speed in the watershed were represented by the NOAA weather station in Sommerville Sommerset airport (station ID: KSMQ). Solar radiation was computed by the SWAT model since no measured solar radiation is available. These gauges were selected because they represent weather stations with available long-term data closest to the study area. Weather stations locations with respect to the project site are shown in Figure 2.5.

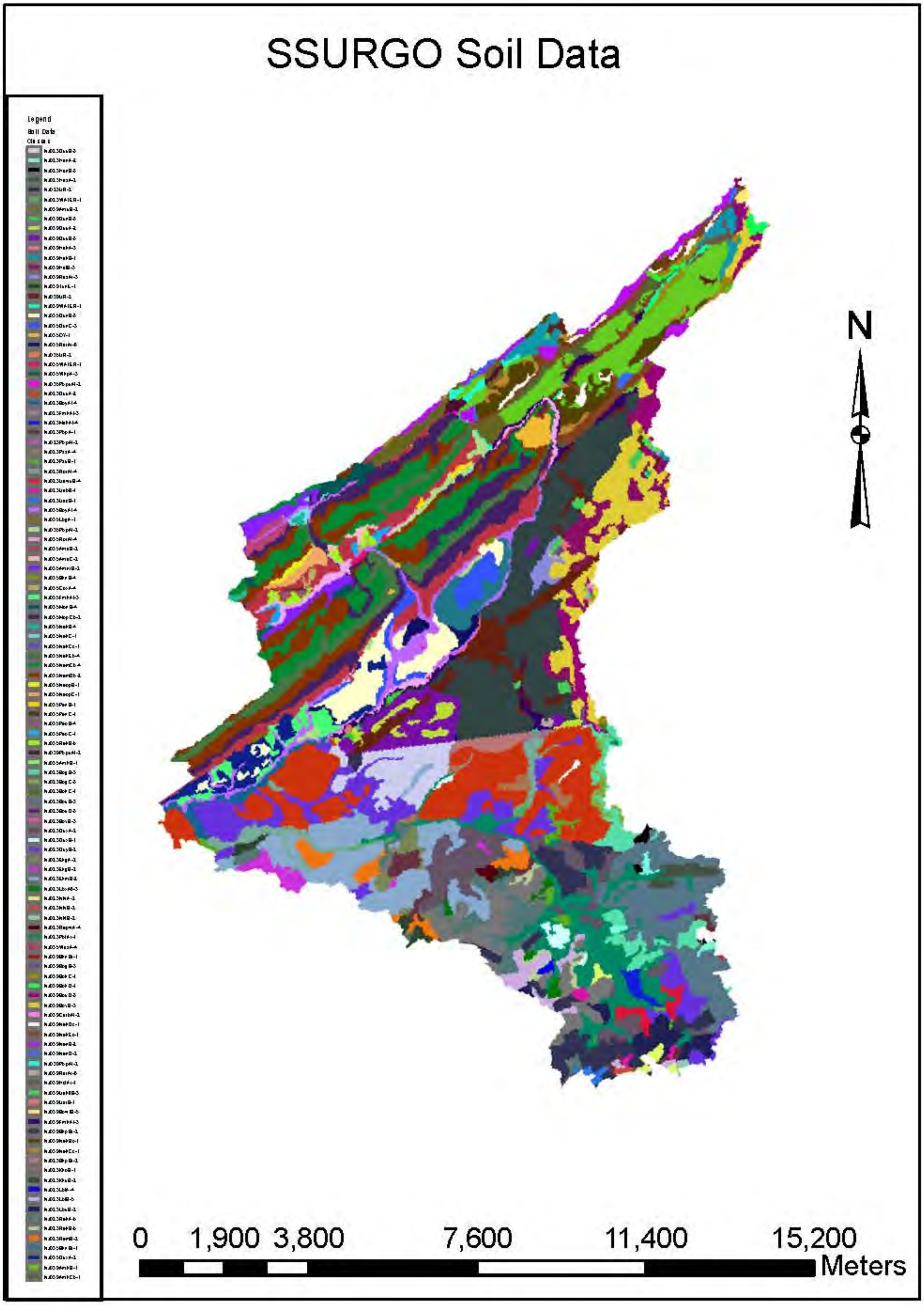


Figure 2.4: Watershed Soil Data for the Bound Brook and Green Brook Watersheds

Table 2.2: Soil Group Percent Areas

Soil Type	Area (%)	Soil Type	Area (%)	Soil Type	Area (%)	Soil Type	Area (%)
NJ023DuuB-3	1.70%	NJ023PbpA-1	0.50%	NJ035PeoB-4	0.10%	NJ039CarbAt-2	0.00%
NJ023HanA-2	0.20%	NJ023PbpAt-2	0.00%	NJ035PeoC-1	0.20%	NJ039NehDc-1	0.30%
NJ023HanB-3	0.10%	NJ023PssA-4	0.30%	NJ035RehB-5	0.20%	NJ039NehEc-1	1.30%
NJ023HasA-2	0.40%	NJ023PsuB-1	0.40%	NJ039PbpuAt-2	0.20%	NJ039NenB-2	0.90%
NJ023UR-2	2.30%	NJ023RorAt-4	0.90%	NJ035AmhB-1	0.00%	NJ039NenD-2	0.20%
NJ023WATER-1	0.10%	NJ023UdwuB-4	0.30%	NJ023BogB-3	1.30%	NJ039PbpAt-2	0.20%
NJ039AmuB-2	0.80%	NJ023UdbB-1	0.10%	NJ023BogC-3	0.20%	NJ039RarAr-6	0.10%
NJ039DunB-3	0.10%	NJ023UdcB-1	0.10%	NJ023BohC-1	0.00%	NJ039HctAr-1	0.10%
NJ039DuuA-2	0.50%	NJ035BoyAt-4	1.60%	NJ023BouB-3	3.70%	NJ039UdkttB-3	0.20%
NJ039DuuB-3	1.40%	NJ035PbpAt-2	0.40%	NJ023BouD-3	0.00%	NJ039UdrB-1	0.00%
NJ039HakA-3	0.00%	NJ035RorAt-4	0.70%	NJ023BovB-3	0.00%	NJ039BowtB-5	0.10%
NJ039HakB-1	0.80%	NJ035AmdB-2	2.90%	NJ023DuxA-2	2.60%	NJ039FmhAt-3	0.70%
NJ039HatB-3	1.30%	NJ035AmdC-2	0.10%	NJ023DuxB-1	0.30%	NJ039BhpBr-2	7.00%
NJ039RasAr-3	0.30%	NJ035AmnrB-2	0.70%	NJ023DuyB-2	3.90%	NJ039NehBc-1	1.40%
NJ039TunE-1	0.00%	NJ035BhnB-4	0.00%	NJ023EkgA-2	0.40%	NJ039NehCc-1	0.30%
NJ039UR-2	2.10%	NJ035CoxA-4	0.10%	NJ023EkgB-2	0.40%	NJ023BhpBr-2	0.30%
NJ039WATER-1	0.10%	NJ035FmhAt-3	0.60%	NJ023EkmB-2	3.70%	NJ023KkoB-1	2.20%
NJ035DunB-3	1.90%	NJ035MonB-4	0.40%	NJ023LbxA6-3	0.20%	NJ023KkuB-2	0.30%
NJ035DunC-3	0.90%	NJ035MopCb-2	3.80%	NJ023NkrA-2	0.20%	NJ023LbtA-4	0.10%
NJ035QY-1	0.40%	NJ035NehB-4	0.10%	NJ023NkrB-2	0.00%	NJ023LbtB-5	0.60%
NJ035RarAr-6	0.30%	NJ035NehC-1	0.10%	NJ023RepwA-4	0.10%	NJ023LbuB-2	0.80%
NJ035UR-2	0.00%	NJ035NehCc-1	0.00%	NJ023PbtAr-1	3.80%	NJ023RehA-5	1.40%
NJ035WATER-1	0.10%	NJ035NehEb-4	2.30%	NJ035WasA-4	0.30%	NJ023RehB-5	0.30%
NJ035WhpA-3	0.00%	NJ035NemCb-4	4.20%	NJ039BhnBr-1	0.00%	NJ023RemB-2	0.80%
NJ035PbpuAt-2	0.00%	NJ035NemDb-2	3.90%	NJ039BogB-3	0.10%	NJ035BhnBr-1	0.90%
NJ023DuuA-2	6.30%	NJ035NeopB-1	0.10%	NJ039BohC-1	0.40%	NJ035DuxA-2	1.00%
NJ023BoyAt-4	0.50%	NJ035NeopC-1	0.30%	NJ039BohD-1	0.20%	NJ039AmhB-1	3.30%
NJ023FmhAt-3	0.10%	NJ035PenB-1	0.10%	NJ039BouD-3	1.00%	NJ039AmhCb-1	0.40%
NJ023MakAt-4	0.20%	NJ035PenC-1	0.00%	NJ039BovB-3	3.10%		

Daily precipitation measured at the Plainfield and Bound Brook gauges from 2004 to 2011 are depicted in Figure 2.6. Note that precipitation data are not available at the Plainfield gauge for part of 2008 and for the entire 2009 year. When data for both gauges were available, they were averaged; when the data from the Plainfield gauge was not available, the NOAA gauge was used. A plot of daily precipitation recorded at both stations (Figure 2-7) reveals significant scatter around the 1 to 1 line. This evaluation suggests that there are spatial differences in the daily precipitation amounts recorded at the two stations.

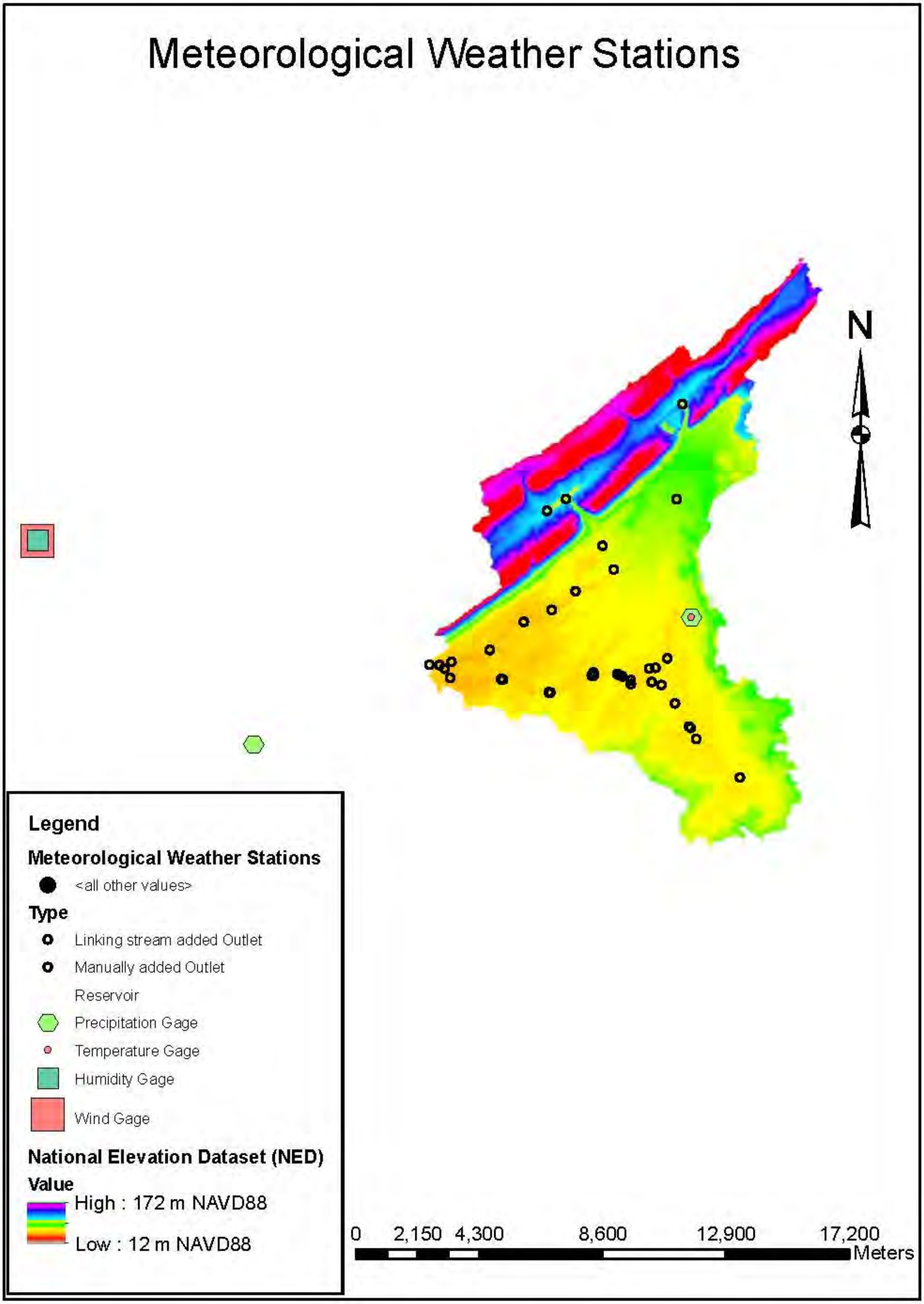


Figure 2.5: Meteorological Weather Stations

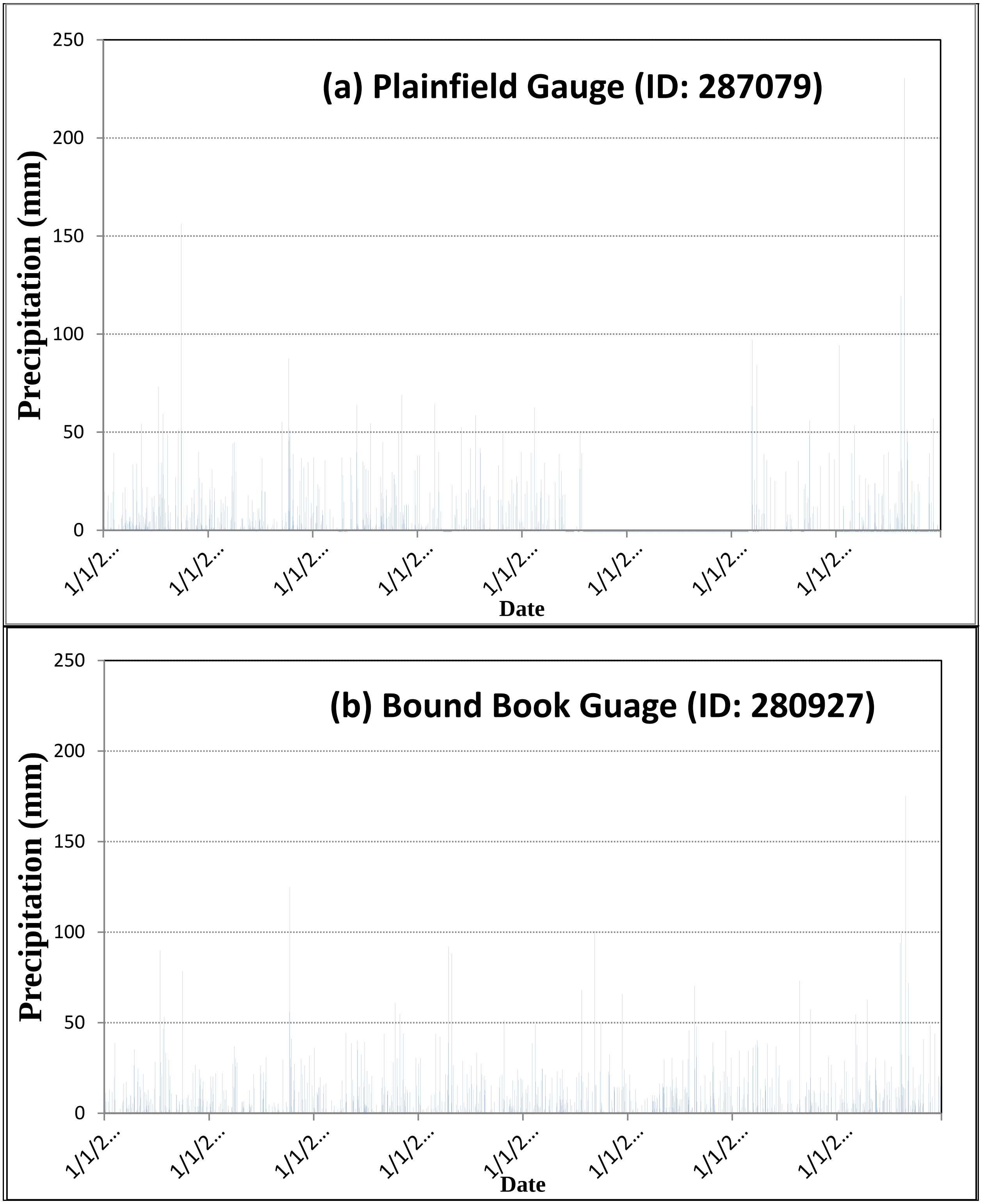


Figure 2.6: Time Series of Daily Precipitation (mm) from 2004-2011 at Plainfield and Bound Brook (NOAA) Gauges.

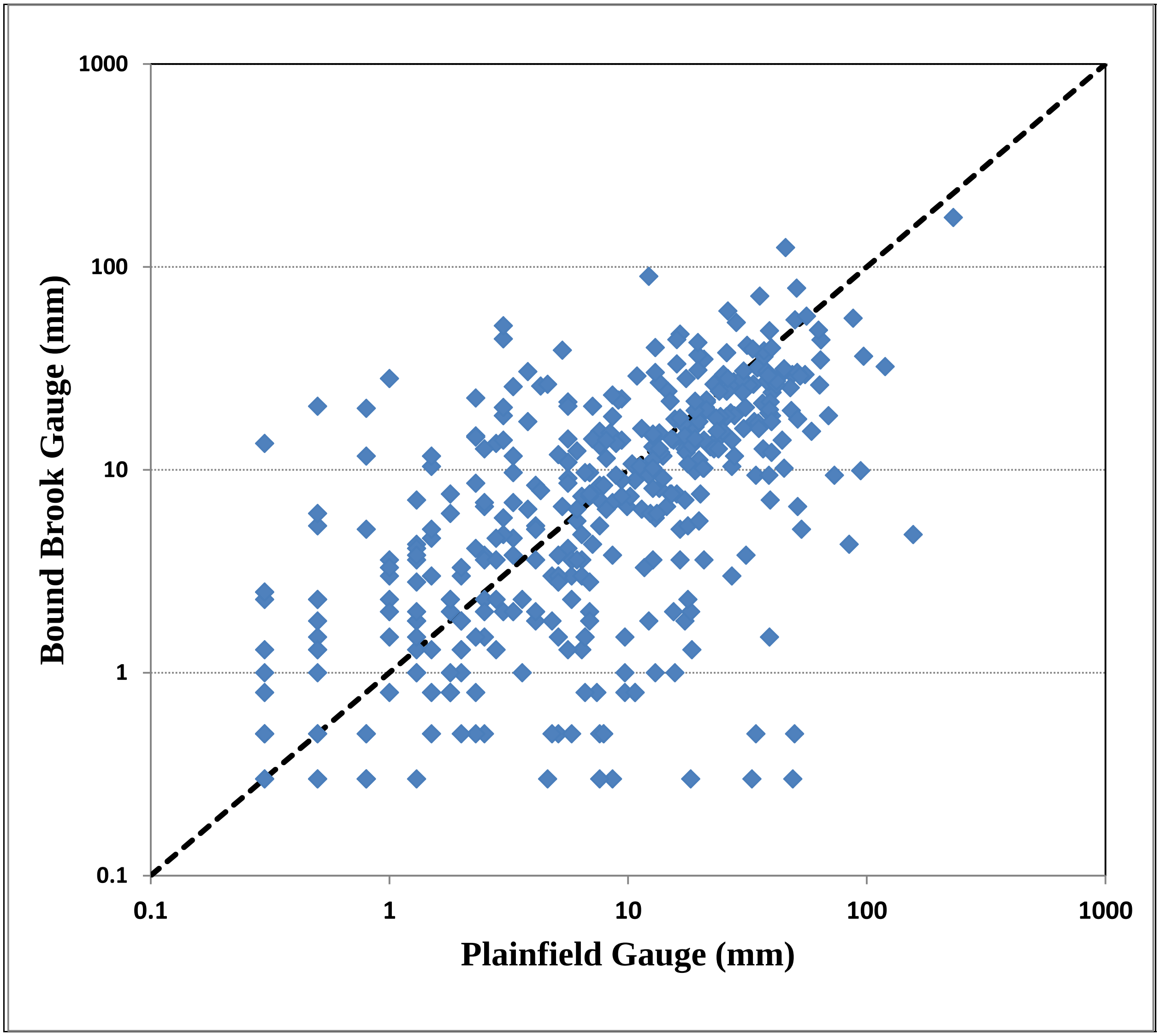


Figure 2.7: Scatter Plot (and Comparison) of Daily Precipitation (mm) recorded at Plainfield and Bound Brook Gauges.

2.4.5. Observed/Measured Flow Data

The calibration and validation of the entire Bound Brook/Green Brook SWAT watershed model were performed based on stream flow measurements at the USGS stream gauge at Middlesex, NJ (Gauge ID: 01403900; see Figure 2.1). A time series of daily flows measured at this station is presented in Figure 2.8 which indicates that the maximum stream flow of 4,440 cfs was observed on the 8/28/2011 (Hurricane Irene) when the maximum precipitation was also recorded by the precipitation gauges. However, other peaks in stream flow on 3/14/2010 (3,500 cfs) and 4/16/2007 (4,240 cfs) are not coincident with the corresponding peaks in precipitation. These differences in precipitation and observed stream flows contribute to the uncertainties in the simulation of watershed surface runoff and sediments yield.

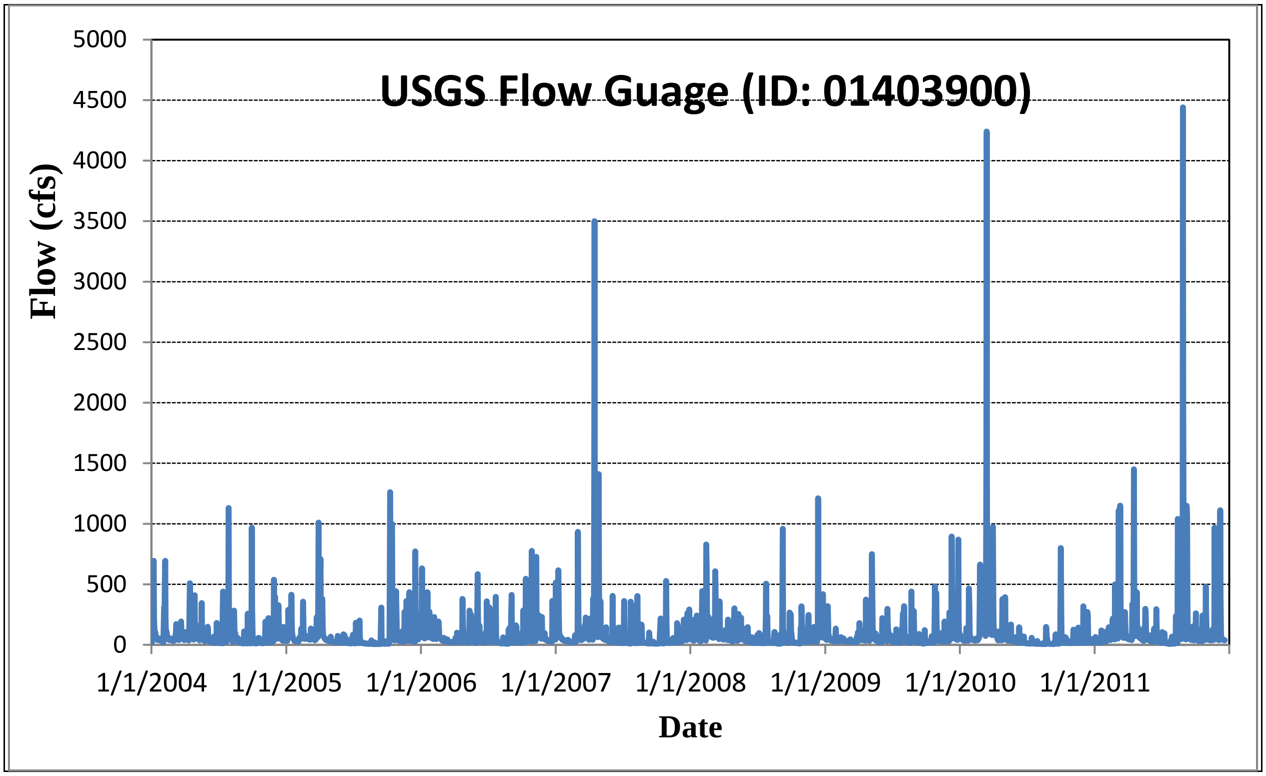


Figure 2.8: Time series of flow (cfs) at USGS Stream Gauge (ID: 0143900)

2.4.6. Observed Suspended Solids and Sediment Load rating Curve

At the USGS Gauge station (ID: 0143900), there are discrete data collected once of month for water quality. Paired suspended solids concentrations and corresponding flows (Figure 2.9) show a general increase in concentration at higher flows. Most of the available data were collected at flows less than 1200 cfs. Notably, there is a single observation at a flow of 2,800 cfs, for which the suspended solids concentration was reported at 65 mg/L. This low suspended solids concentration at such a high flow might indicate that suspended solids can be depleted during a flood event. (This point is not considered an outlier and was maintained in the analysis).

In general, a rainstorm causes an increase in discharge, erosion and transport of soil particles from the watershed into its streams, and an associated increase in turbulence in the stream. Within the stream, this turbulence re-suspends bed sediment and together with the sediment transported from the watershed soils, can result in high concentrations of suspension solids in the water. During prolonged rainstorms, discharge and turbulence may remain high but there is usually a progressive decline in the quantity of suspended material present in the water. This is because the quantity of sediment on a river bed, and which is introduced into the river by erosional processes, is limited and the amount of sediment available to be taken into suspension gradually diminishes during a storm event. These observations typically manifests when a series of discharge measurements and water samples are taken at intervals throughout a storm event (when flow increases, reaches a peak, and then decreases), in the form of a loop called a hysteresis loop (Ongley, 1996). Hysteresis may also be observed in plots of seasonal data. This reflects periods of the year when sediment may be more readily available than at other times. Higher TSS concentrations may occur, for example, after a long, dry period or in dry months when vegetation is not able to hold back soil particles that are being eroded.

Using the discrete suspended solids and flow data, a sediment rating curve was developed (Figure 2.10). The most commonly used sediment rating curve is an empirical power function that relates sediment concentration or sediment load (the product of concentration and flow) to flow (Asselman, 1999; Rondeau, 2000). In this study this relationship was derived by performing a log-log regression in log of the sediment load versus log of flow and a strong relationship (R^2 = 0.89) was obtained. Because the regression was performed in log units, any prediction of load at a particular level of flow will be equivalent to a median load. In addition to the median regression line, the 95 percent prediction interval (PI) is also included in the plots. The PI is the confidence interval for prediction of an estimate of an individual load for a corresponding flow value at which the load estimate is required. The PI incorporates the unexplained variability of sediment load in addition to uncertainties in the regression parameter estimates. The sediment rating curve developed in this study was used to predict median daily loads of suspended sediments based on daily flows from 2005 to 2011, and their associated uncertainty. These median daily loads and uncertainty were compared to model estimates of sediment yield derived from SWAT. It is important to note that because the majority of the data are available for flows less than 1200 cfs, the rating curve prediction for flow higher than 1200 cfs is based on extrapolation of the regression function and subject to greater uncertainty. Furthermore, the regression function as assumes that as flow increases suspended solids load will increase without limit, as assumption that is problematic in hysteresis occurs. Despite these limitations, this rating curves provides a good basis for comparison to SWAT model results.

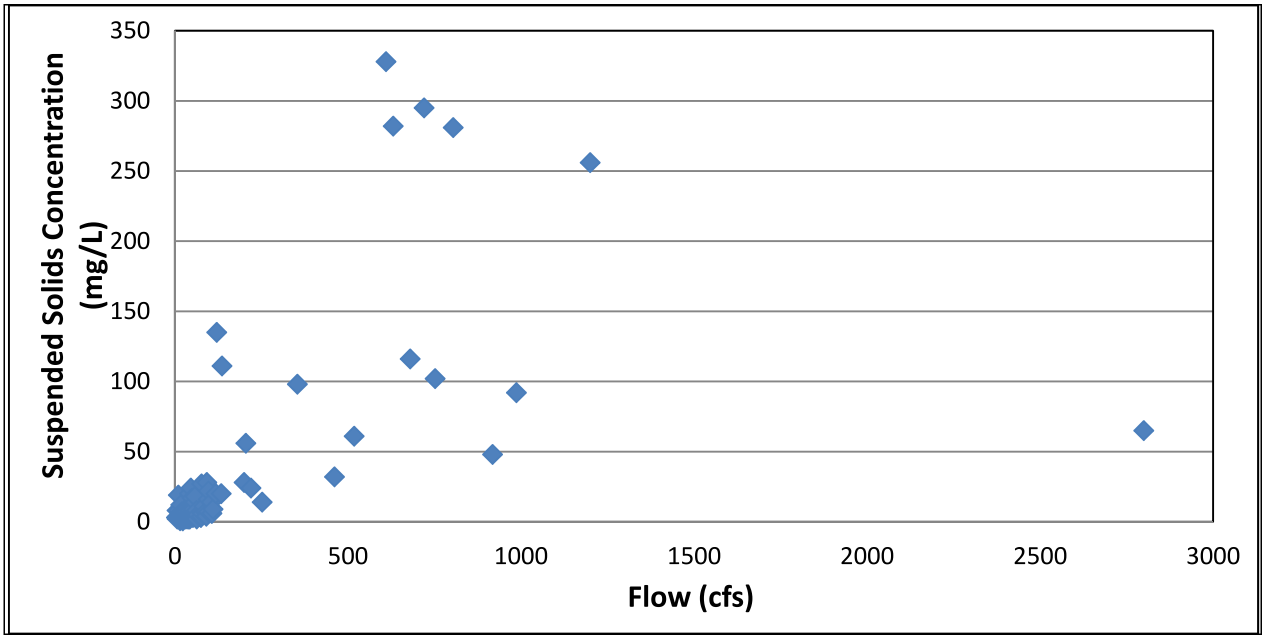


Figure 2-9: Suspended Solids concentration (mg/L) versus flow (cfs) at USGS Stream Gauge (ID: 0143900).

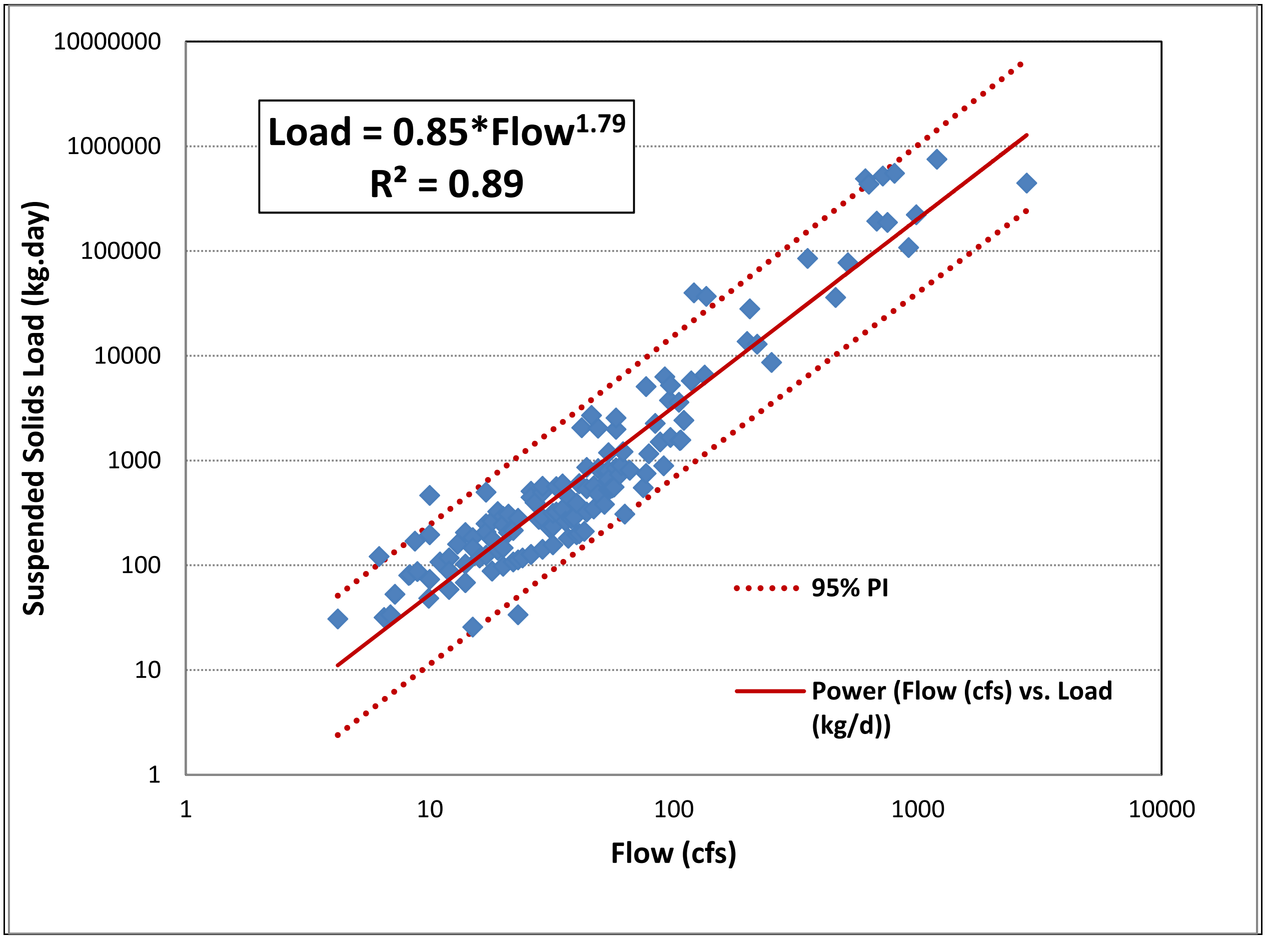


Figure 2.10: Sediment Rating Curve for USGS Stream Gauge (ID: 0143900) showing median prediction regression line and 95% prediction intervals.

2.5. Model Calibration for Flow

The SWAT model was run from 2004 to 2007. The year 2004 was used as the warm up period. Calibration was done from 2005 to 2007. Because SWAT's input parameters are physically based, they must be held within a realistic uncertainty range during calibration. The calibration procedure used in this study is consistent with the application of SWAT CUP outlined in Arnold *et. al.*, (2012) as follows:

- Develop initial or default SWAT input parameters (as created by ArcSWAT) and prepare the input files for SWAT-CUP.
- Run the SWAT model with initial parameters and plot the simulated and observed variables at each gauging station for the entire period of record.
- Determine the most sensitive parameters for the observed values of interest.

- Assign an initial uncertain range to each parameter globally, by scaling the parameters identically for each HRU.
- Run the SWAT-CUP-SUFI2 model several times and view the results for the gauged outlet.
- Perform the global sensitivity analysis and use the statistical output to eliminate non-sensitive parameters from the calibration process.
- Evaluate model performance.

The model performance of the calibration was evaluated qualitatively based on visual comparison of the monthly observed flows and the model simulated values, and quantitatively by the Nash-Sutcliff Index (NSE), and the coefficient of determination (R^2). The NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. NSE is computed as:

$$NSE = 1 - \frac{\sum(O - S)^2}{\sum(O - \bar{O})^2}$$

Where, O and S are observed and simulated values, respectively. Ō is the mean observed values. NSE values range between -∞ and 1 with NSE of 1 indicating a perfect simulation. Simulation results are often considered to be satisfactory when NSE is greater than 0.5.

The coefficient of determination (R^2) is a measure of collinearity between observed and simulated data, and ranges between 0 and 1, is estimated as:

$$R^2 = \frac{[\sum(O - \bar{O})(S - \bar{S})]^2}{[\sum(O - \bar{O})^2][\sum(S - \bar{S})]^2}$$

Although $R^2 > 0.5$ is acceptable for modeling, a higher value is considered better. For this calibration, the model simulation was considered reasonable when both NSE and R^2 exceeded about 0.5.

Using the procedures outlined above for calibration using SWAT-CUP, a sensitivity analysis focusing on 12 parameters was conducted (Table 2.3). Based on the t-statistics and associated p-values, several of these parameters were determined to be sensitive parameters (p-value < 0.05). Although all 12 parameters were maintained during calibration, as SWAT cup randomly varied them between upper and lower bounds during 300 Monte-Carlo simulations to determine the best parameter fit. The range of values used during the calibration and the best parameter values are given in Table 2.4. The model calibrated flows using the best parameter values are shown in Figure 2.11. The high NSE and R^2 for the calibrated model simulation of 0.60 and 0.75 suggest that the calibrated model flows provides a good fit to the observed flows.

Table 2.3: Global Sensitivity Output for 12 Model Parameters

Parameter Name	Description	Process	t-Stat	P-Value
CN2	Curve number	Surface runoff	120.11	0.00
GW_REVAP	Revamp Coefficient	Groundwater	-11.86	0.00
SOL_BD(1)	Moist bulk density	Groundwater	-8.99	0.00
ESCO	Soil evaporation coefficient	Evapotranspiration	7.83	0.00
GW_DELAY	Groundwater delay time	Groundwater	-6.08	0.00
CH_N2	Manning's coefficient for main channel	Surface runoff	-5.21	0.00
GWQMN	Depth of water in shallow aquifer	Groundwater	-3.62	0.00
SOL_K(1)	Saturated hydraulic conductivity	Groundwater	3.24	0.00
ALPHA_BF	Base flow recession coefficient	Groundwater	2.51	0.01
SFTMP	Snowfall temperature	Snow	-1.37	0.17
ALPHA_BNK	Base flow alpha factor for bank storage	Groundwater	0.83	0.41
SOL_AWC(1)	Available water capacity	Groundwater, evaporation	-0.70	0.48

Table 2.4: Range of Values Used during the Calibration and the Best Parameter Values

Parameter Name	Units	Best Estimate	Lower Bound	Upper Bound
CN2	%	-0.49	-0.5	-0.2
ALPHA_BF	Days	0.74	0.0	1.0
GW_DELAY	Day	448	30	450
GWQMN	mm	0.64	0.0	2.0
GW_REVAP	-	0.15	0.0	0.2
ESCO	-	0.83	0.8	1.0
CH_N2	-	0.29	0.0	0.3
ALPHA_BNK	Days	0.28	0.0	1.0
SOL_AWC(1)	%	0.11	-0.2	0.4
SOL_K(1)	%	0.79	-0.8	0.8
SOL_BD(1)	%	-0.43	-0.5	0.6
SFTMP	^{o}C	1.35	-5.0	5.0

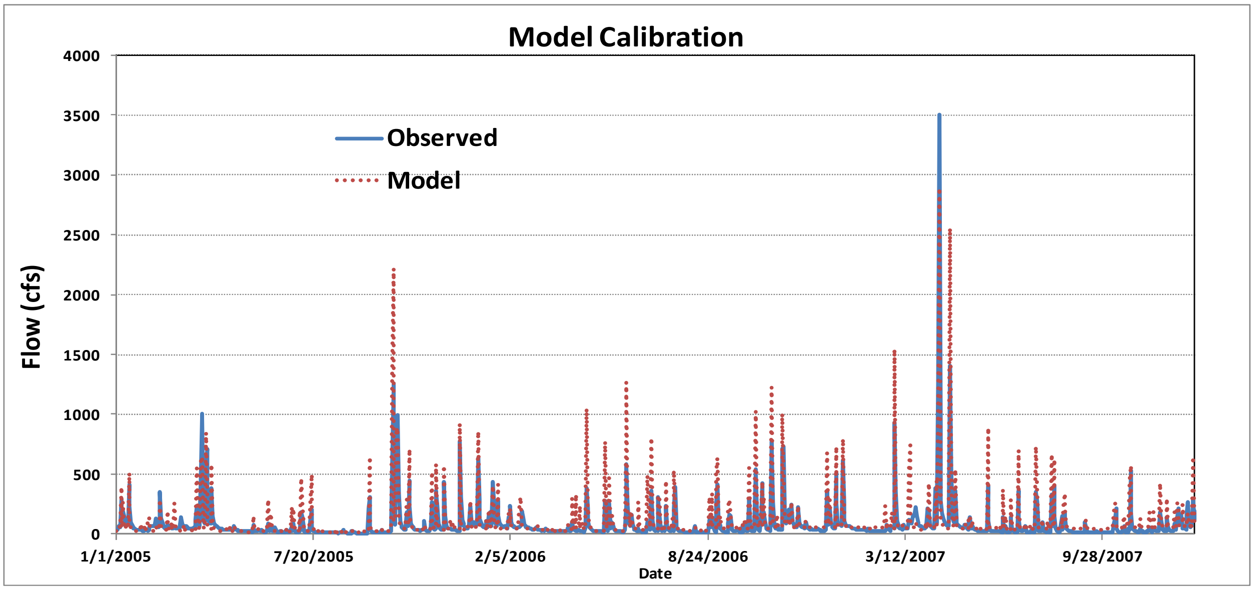


Figure 2.11: Observed daily flows and model best estimation at the USGS Gauging station during calibration period (2005 – 2007). Model fit: NS = 0.6; R^2 = 0.75.

2.6. Model Validation for Flow

The best estimated parameter values from the calibration were applied to simulate the validation period of 2008 – 2011. Figure 2.12 shows the model validation results. In general, the model shows a good fit (R^2 = 0.6) with the observed flows, although the NS of 0.3 was lower than the target of 0.5. The model over-predicts flows during storms, including flows for Hurricane Irene, which occurred in August 2011. It is important to note that uncertainties in model results are not only related to calibrated parameters, but also to uncertainties in other inputs like precipitation and temperature.

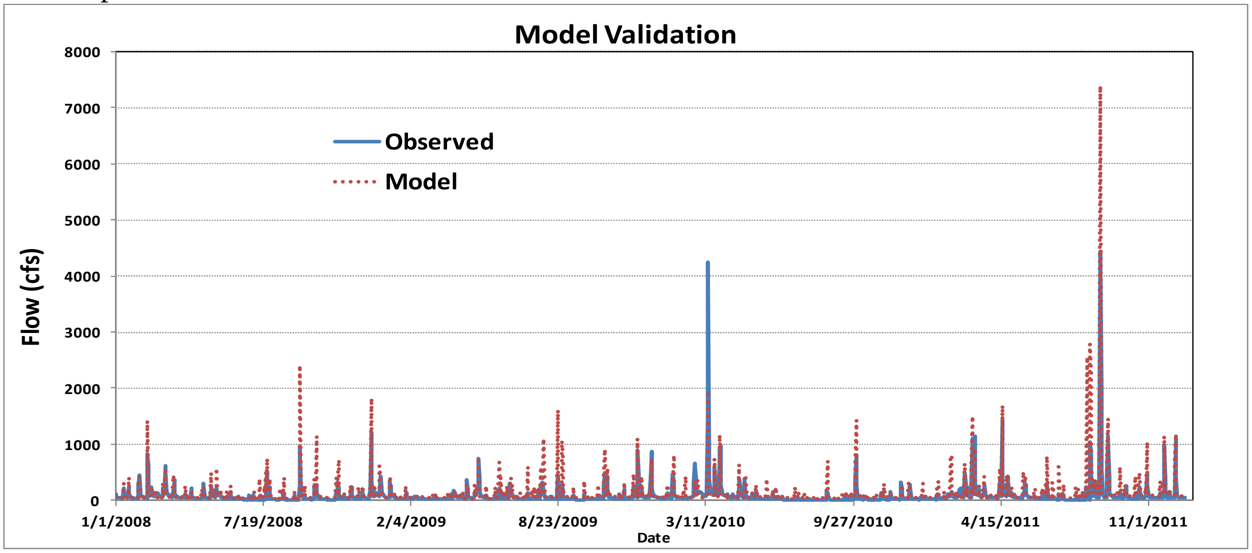


Figure 2.12: Observed daily flows and model best estimation at the USGS Gauging station during validation (2008-2011). Model fit: NS = 0.3; R^2 = 0.6.

2.7. Watershed Sediment Yield

The simulated sediment yield (based on Equation 2) was compared to values derived from the rating curve (described in Section 2.4.6 for the USGS Stream Gauge on a monthly basis),which was based on the observed TSS concentrations (Figure 2.13). In general, the simulated sediment yield was higher than the observed sediment yield during higher precipitation and runoff events. Although there is an observed difference between the two sediment yields, the model prediction generally falls within the 95 percent PI; consequently, the difference is not statistically significant. The sediment yield simulated by the model in various reaches and subbasins were saved and passed onto the SIAM model as described in Section 4.

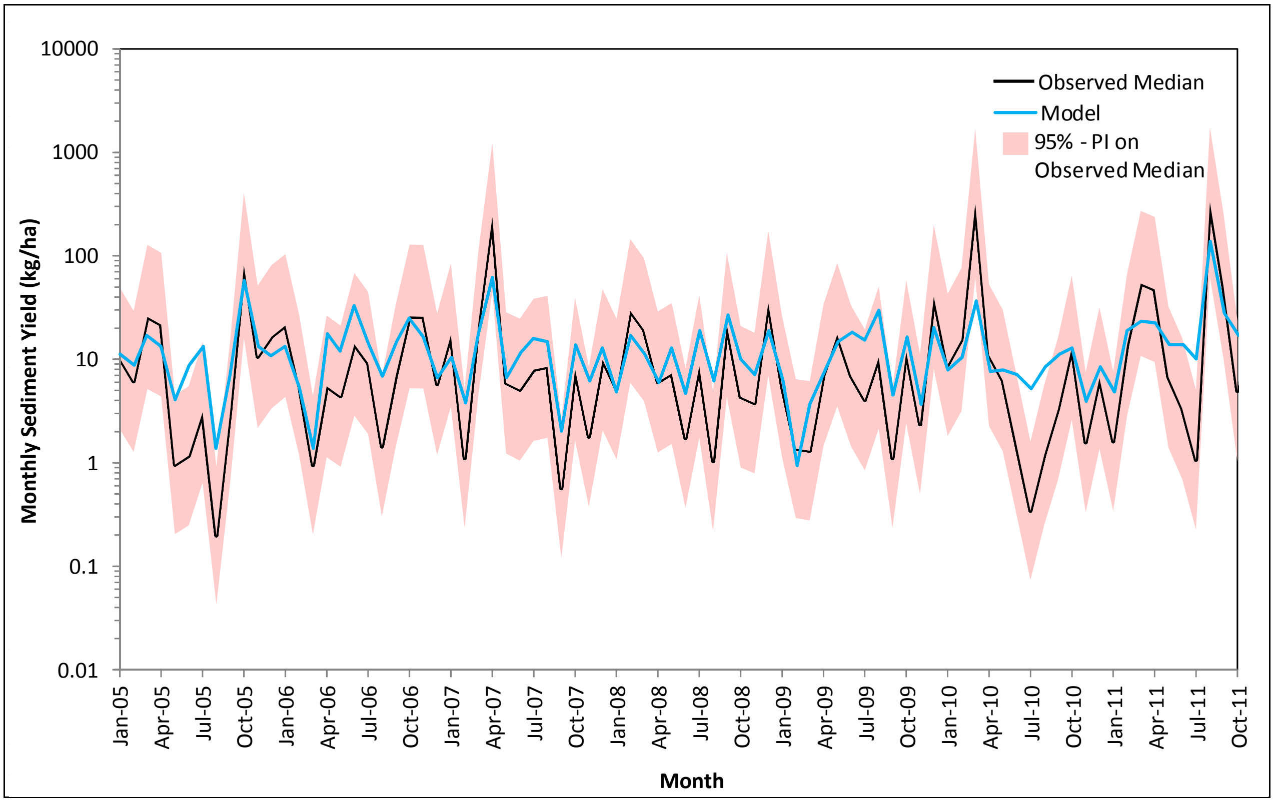


Figure 2.13: Comparison of Model Simulated Monthly Sediment yield (kg/ha) with Median Sediment Yield and 95 percent PI Derived from Rating Curve for USGS Stream Gauge (ID: 0143900).

3. Hydraulics Modeling

For stream hydraulics modeling, the Hydrologic Engineering Centers River Analysis System (HEC-RAS) was used. Hydrologic Engineering Centers River Analysis System (HEC-RAS) is a one-dimensional model, intended for hydraulic analysis of river channels. The model is comprised of a graphical user interface, separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities. The HEC-RAS system includes four river analysis components. Based on the laws on conversation of energy, HEC-RAS model uses physical field measurements of the stream and floodplain cross sections to simulate flow related values including: flow rates, velocity, energy, and water surface elevation.

The main inputs to the model are:

- River geometric data: width, elevation, shape, location, length;
- River floodplain data: length, elevation;
- Manning roughness coefficient[3] (Manning 'n' values) for the landuse type covering the river and the floodplain area;
- Boundary conditions *e.g.* slope, critical depth; and,
- Stream discharge values from SWAT model runoff and stream routing result.

The outputs from the model include:

- Water surface elevations;
- Rating curves;
- Hydraulic properties, i.e., energy grade line slope and elevation, flow area, velocity; and,
- Visualization of stream flow, which shows the extent of flooding.

3.1. Channel-Geometry Data

Channel cross-section projections used in the Bound Brook HEC-RAS model were obtained from field surveys conducted by Pennoni Associates during the winter of 2011. All cross-sections were surveyed perpendicular to the channel. The cross-section projections included the channel, banks, and an extended 50 feet onto the floodplain. Maximum distance between adjacent surveyed points was limited to 10 feet so as to accurately survey elevation changes along cross sections. Throughout Bound Brook from RM0 at the confluence with Green Brook to RM7 at the upstream extent of the study area, all in-stream structures including culverts, bridges, spillways, and other features within the channel were field surveyed to obtain elevation

[3] Mannings roughness coefficient incorporates potential presence of debris material in the streambed in the model.

data and structural geometry. Bridge, spillway, and culvert cross-section data were collected at close intervals upstream and downstream of the structures in order to compute the potential backwater effects of these structures. In all, 45 cross sections (of channel and of structure) were surveyed in the winter of 2011 to define channel cross-section geometry for this sediment-transport study. Cross sections data for new Market Pond were obtained from drawings obtained from the township of Piscataway, NJ.

3.2. Floodplain - Contour Data

Pennoni Associates surveyed cross sections only extended 50 feet from both left and right stream bank stations and did not extend far enough to cover the entire floodplain to higher ground which is required for HEC-RAS model to accurately model high flow conditions. Beyond the limits of the site survey, the cross sections were supplemented with additional contours that were generated using the U.S. Geological Survey (USGS) National Elevation Dataset (NED) digital elevation models (DEM). The DEM is available online at the USGS National Map Seamless Server. The DEM used for this purpose has a resolution of 1/9 Arc-Second (approximately 9.84 ft). The DEM data unit was in meters with a geographic projection. It has a vertical datum of NAVD88 in meters and a horizontal projection of NAD83. The resolution of the data was approximately 3 meters with a vertical accuracy of +/- 1 meter. To accurately merge the surveyed data which has a New Jersey State plane coordinate and vertical datum of NAVD88 in feet, the USGS NED data was re-projected to New Jersey State Plane Coordinate with English units (feet). The DEM data were imported into ArcMap 10, and 0.5 meter (approx. 1.6 feet) contour intervals were generated using the Spatial Analyst and the 3D Analyst extensions in ArcGIS.

3.3. Stream Change Location - Flow Data

In order to simulate the entire Bound Brook stream and to check the simulated water surface elevations at certain locations, the use of “multiple flow change junctions” was needed. A stream flow change junction was added at any location where subwatershed runoff is added via a tributary or at a location where model simulated water surface elevations were to be compared against measured data. Overall, about nine flow change locations were identified for the hydraulic modeling as shown in Figure 3.1. This flow data fused for input into HEC-RAS was obtained from the daily flow data predicted by SWAT.

3.4. Manning n-values

The Manning’s n-value is used to help calculate the energy losses between cross sections due to friction. The Manning’s n-value depends on a number of factors which include: surface roughness (including debris), vegetation, channel irregularities, degree of meander, obstructions, size and shape of the channel. In this study, Manning’s n-values used in the hydraulic computations were assigned on the basis of engineering judgment, aerial photographs and field observations of the Brook and floodplain areas.

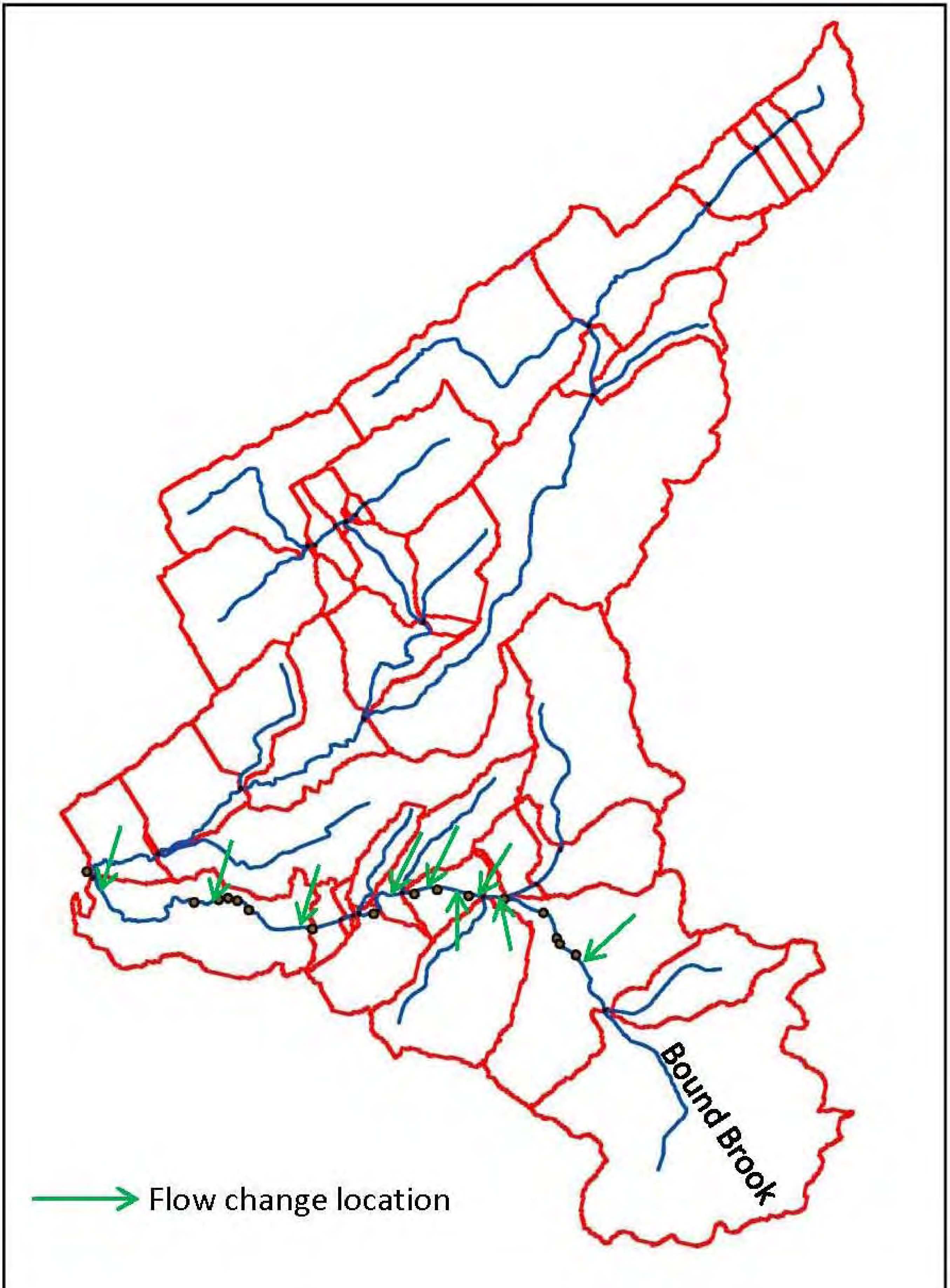


Figure 3.1: Flow change locations

Existing vegetation along the river banks has a substantial influence on hydraulic roughness and the influence varies according to depth and magnitude of flow. Different hydraulic roughness factors were therefore determined for the main channel of flow and the floodplain areas. Channel roughness values were generally low over the extent of the hydraulic model. The final Manning n-values assigned to the various sections were determined by calibration, but they ranged from 0.035 to 0.07 in the channel and from 0.02 to 0.1 on the floodplain.

3.5. Boundary Conditions

In HEC-RAS, boundary conditions are needed to establish the starting water elevation at the ends of Bound Brook study limits (upstream and downstream) and for the model to begin the calculations. For the Bound Brook HEC-RAS model, a mixed flow regime was assumed and for this flow regime, normal depth boundary conditions were used at both ends of the study limits. The normal depths for upstream and downstream boundary conditions were approximated by using the slope of bound Brook bed at those locations respectively.

3.6. Calibration of HEC-RAS Model

The HEC-RAS model was calibrated by adjusting the Manning's roughness coefficient within acceptable limits, to better match the model computed surface water elevation to The Louis Berger Group, Inc., (LBG) field measured surface water elevations. This calibration approach was chosen because roughness parameter together with geometry is considered to have the most important impact on predicting inundation extent and flow characteristics (Aronica *et. al.*, 1998; Bates *et. al.*, 1996; Hankin and Beven, 1998; Hardy *et. al.*, 1999; Rameshwaran and Willetts, 1999; Romanowicz *et. al.*, 1996).

LBG installed eight Solinst level loggers at strategic locations in the Brook within the study area, in 2011, to continuously measure surface water levels that were meant to be used for model calibration and other analysis. Figure 3.1 show the LBG Solinst level logger locations. Only the six level loggers in the main channel were used in the calibration including: Belmont Avenue, Clinton Avenue, South Avenue, Bound Brook Road bridges, manmade dam and New Market Pond.

A comparison of the observed versus simulated water surface elevations are shown in Figures 3.2 through 3.7. As shown in Figures 3.2 through 3.7, the simulated surface water elevations closely match the observed elevations with the exception of the Manmade Dam and South Avenue Bridge locations where there is a vertical shift between observed and simulated water surface elevations. The vertical shift for these two locations appears to be constant and is likely a result of error in recording the level-logger tether length, which is used in converting measured water depth to water elevation.

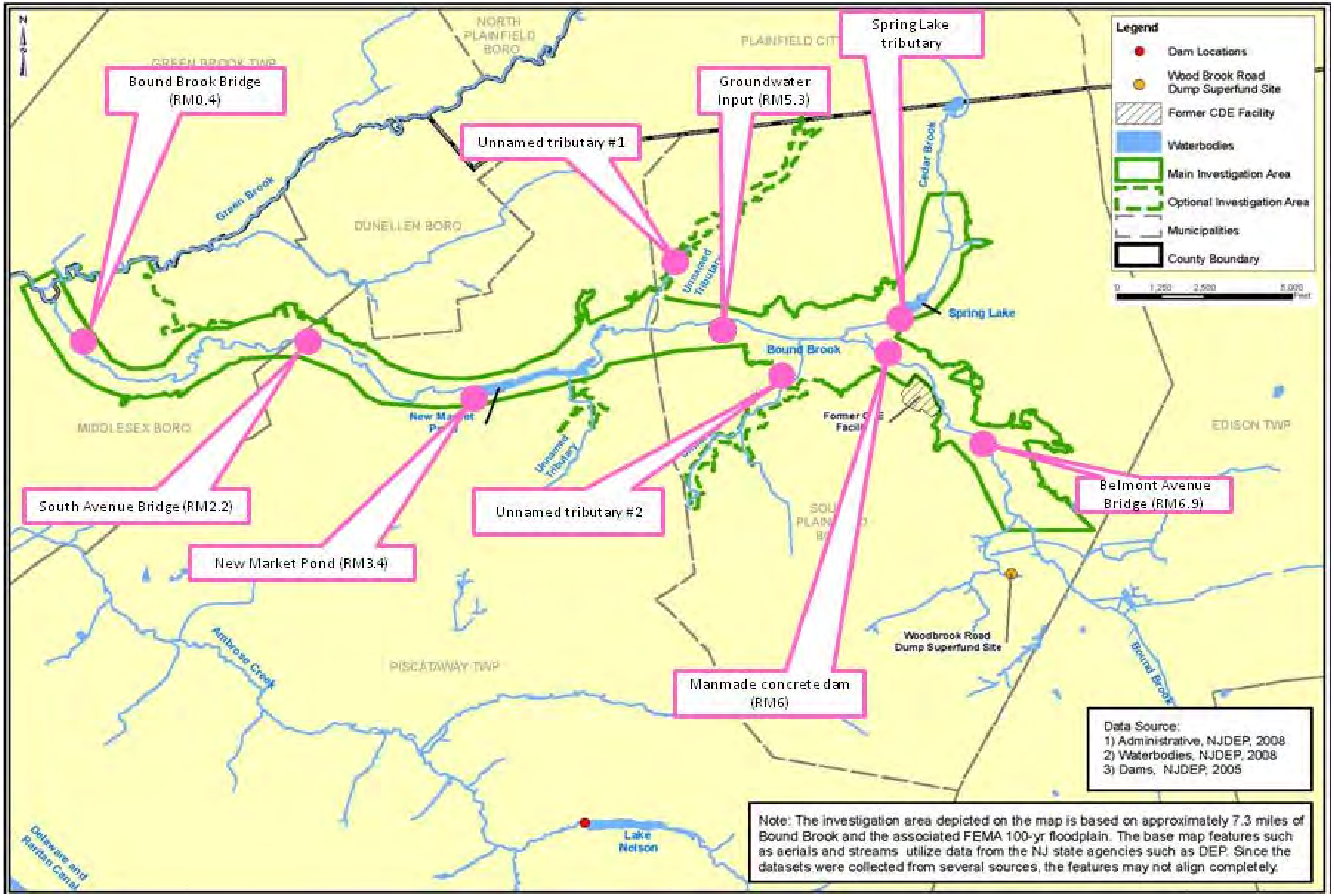


Figure 3.2: Continuous water level measuring locations

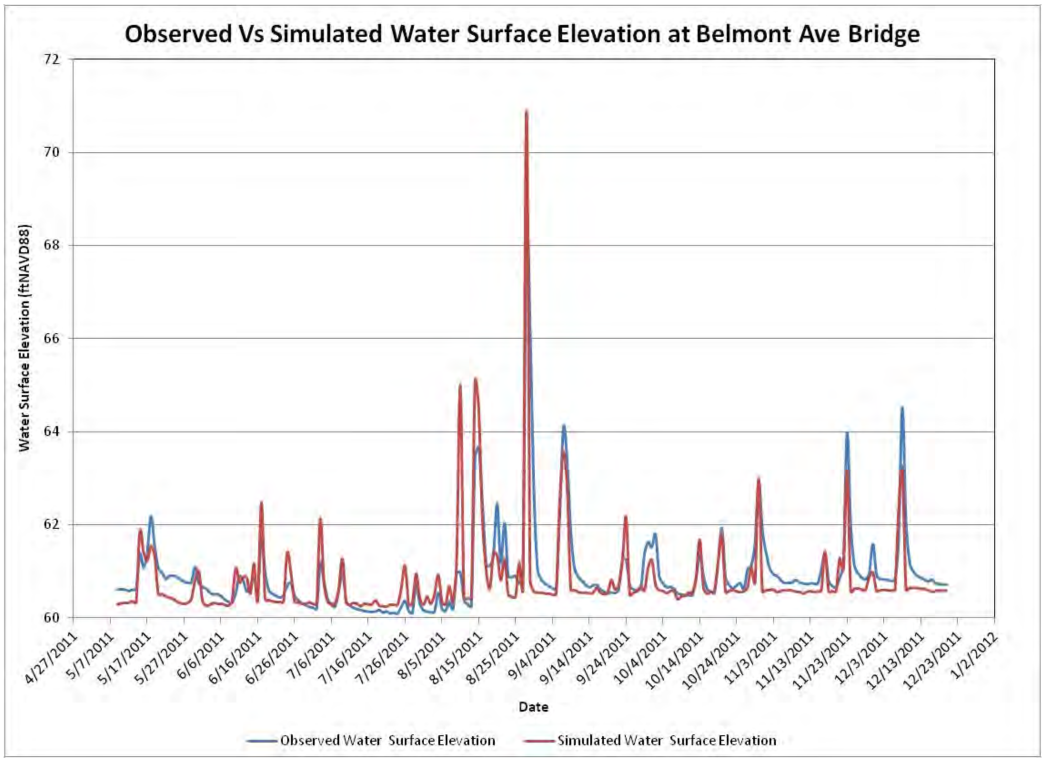


Figure 3.3: Observed versus simulated water surface elevation at Belmont Avenue Bridge

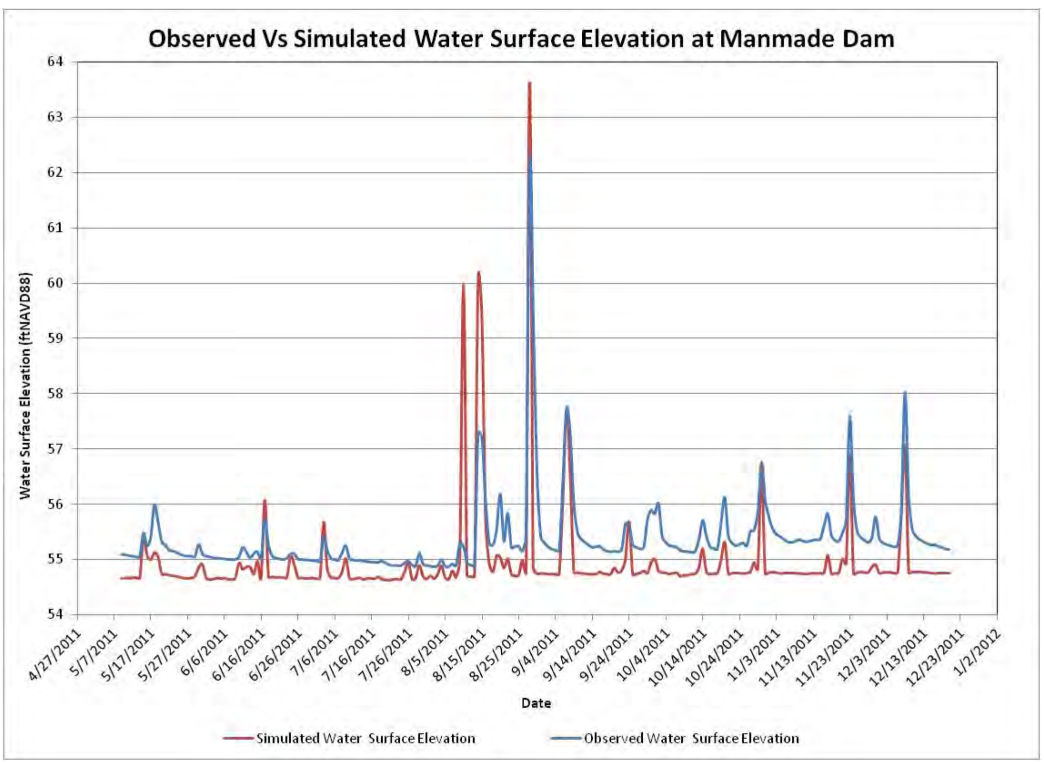


Figure 3.4: Observed versus simulated water surface elevation at Manmade Dam

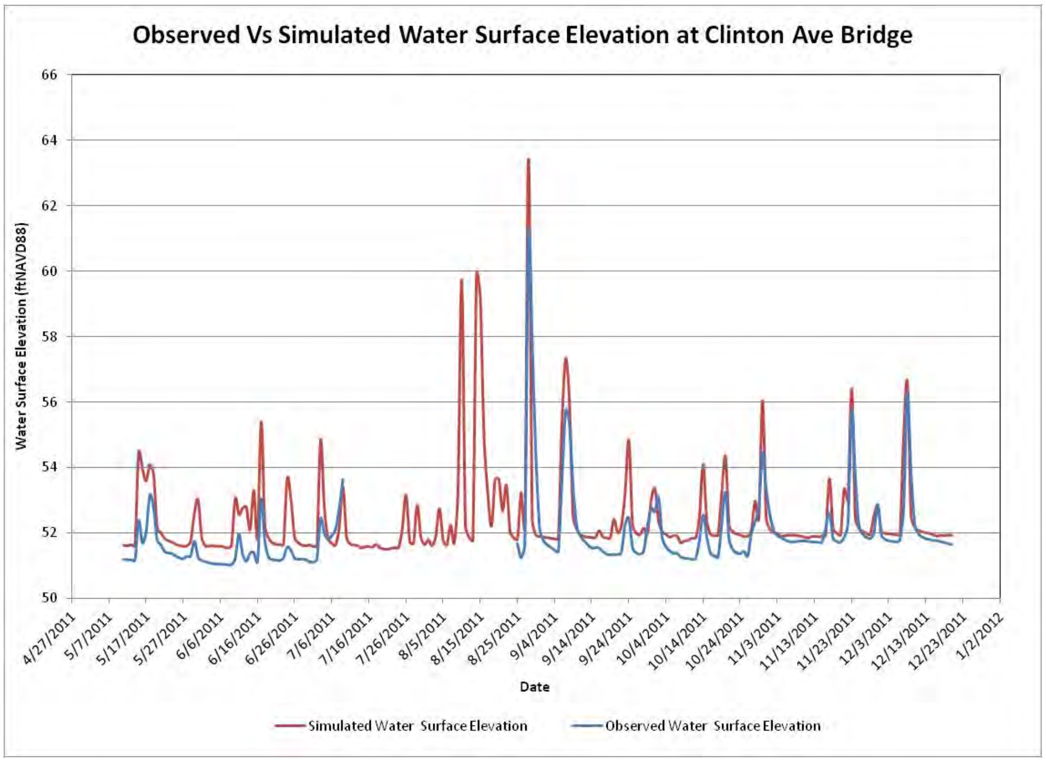


Figure 3.5: Observed versus simulated water surface elevation at Clinton Avenue Bridge

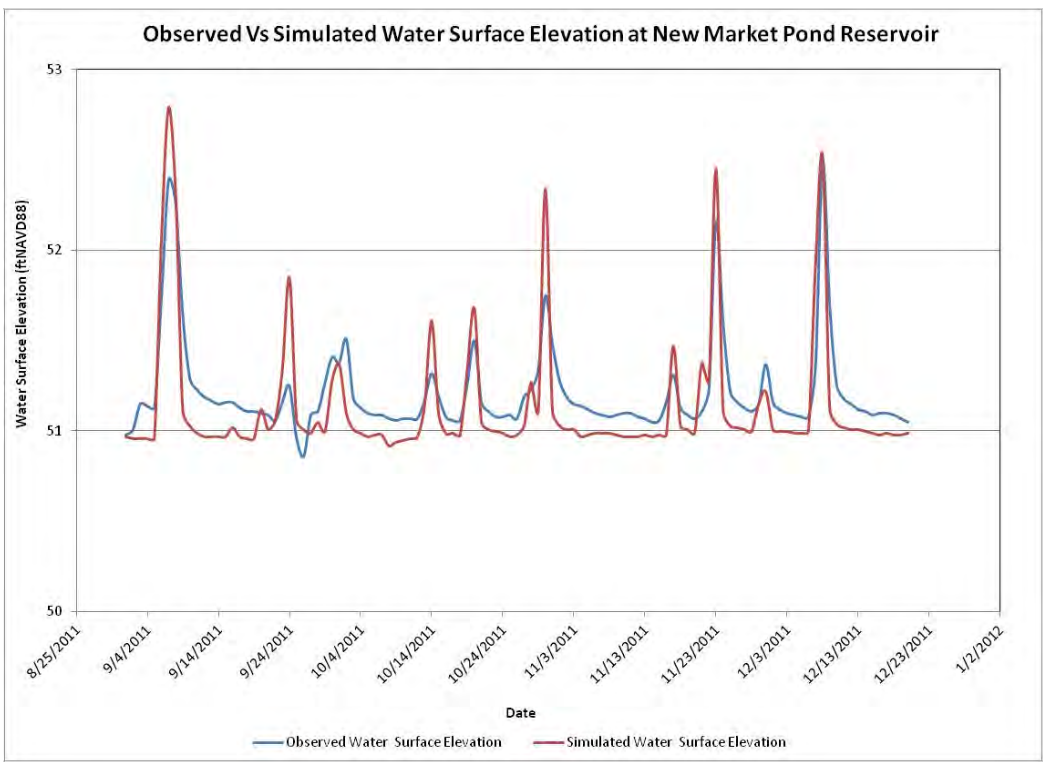


Figure 3.6: Observed versus simulated water surface elevation at New Market Pond Reservoir

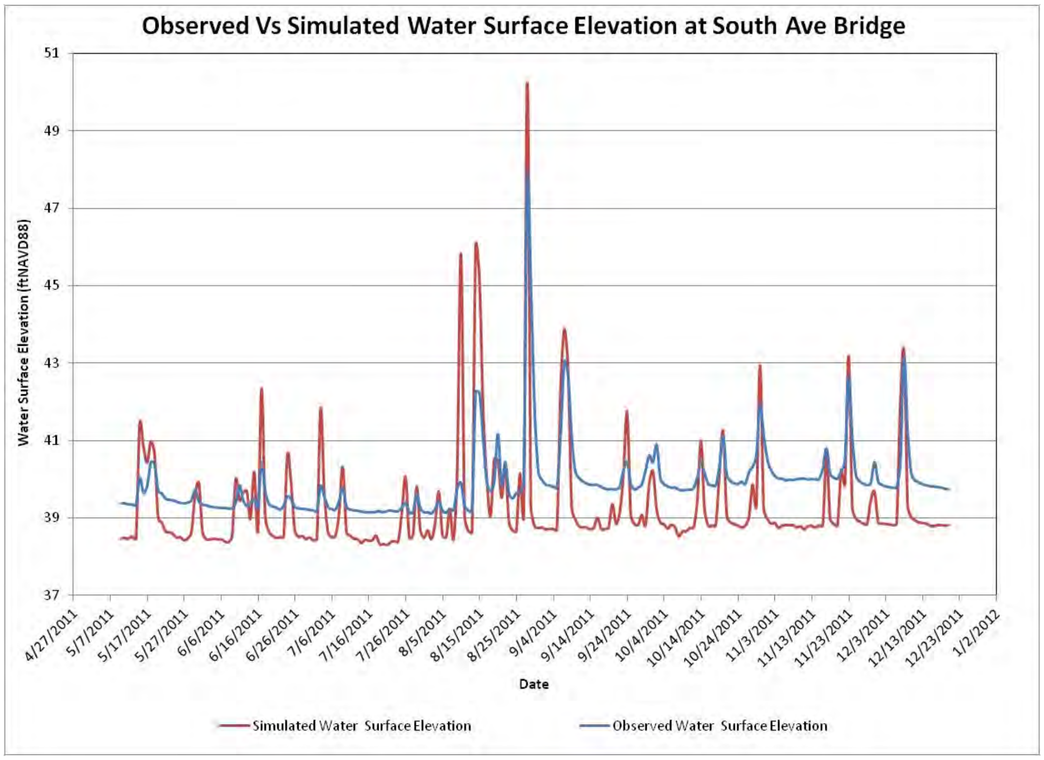


Figure 3-7: Observed versus simulated water surface elevation at South Avenue Bridge

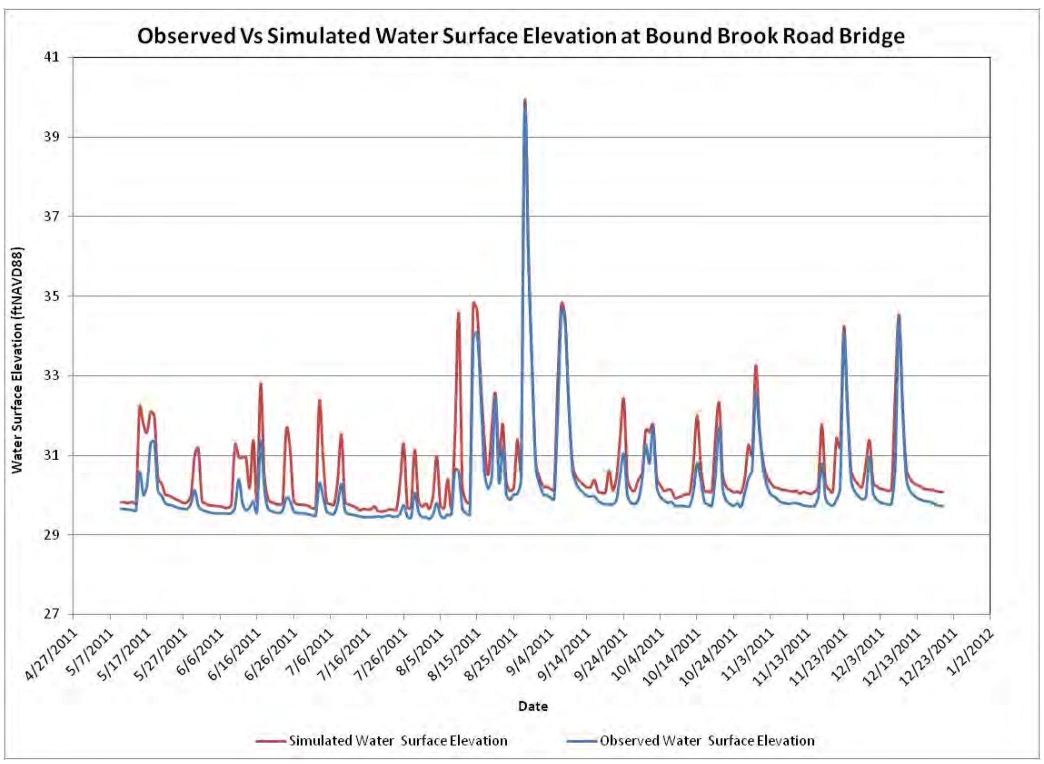


Figure 3.8: Observed versus simulated water surface elevation at Bound Brook Road Bridge

4. Sediment Delivery Analysis – Base Case and FS Scenarios

A sediment assessment model constructed using SIAM feature in HEC-RAS was used to evaluate potential changes in sedimentation patterns that could occur due to remedial alternatives assessed as part of the feasibility studies. SIAM compares the annual sediment transport capacity of a river reach to the annual sediment supply and provides an indication of whether aggradations, degradation, or equilibrium may occur. Initially, a steady-state HEC-RAS model was developed and the hydraulic results were used in the SIAM for analyses. Since HEC-RAS/SIAM model runs under quasi-steady-state condition, the 2005-2011 SWAT model-computed flows were transformed to annualized flow duration values (see Section 4.2.1 for details). Each flow level required for SIAM was modeled in HEC-RAS and the steady state hydraulic results were passed onto SIAM. A schematic showing the sediment balance algorithm in SIAM is provided in Figure 4-1.

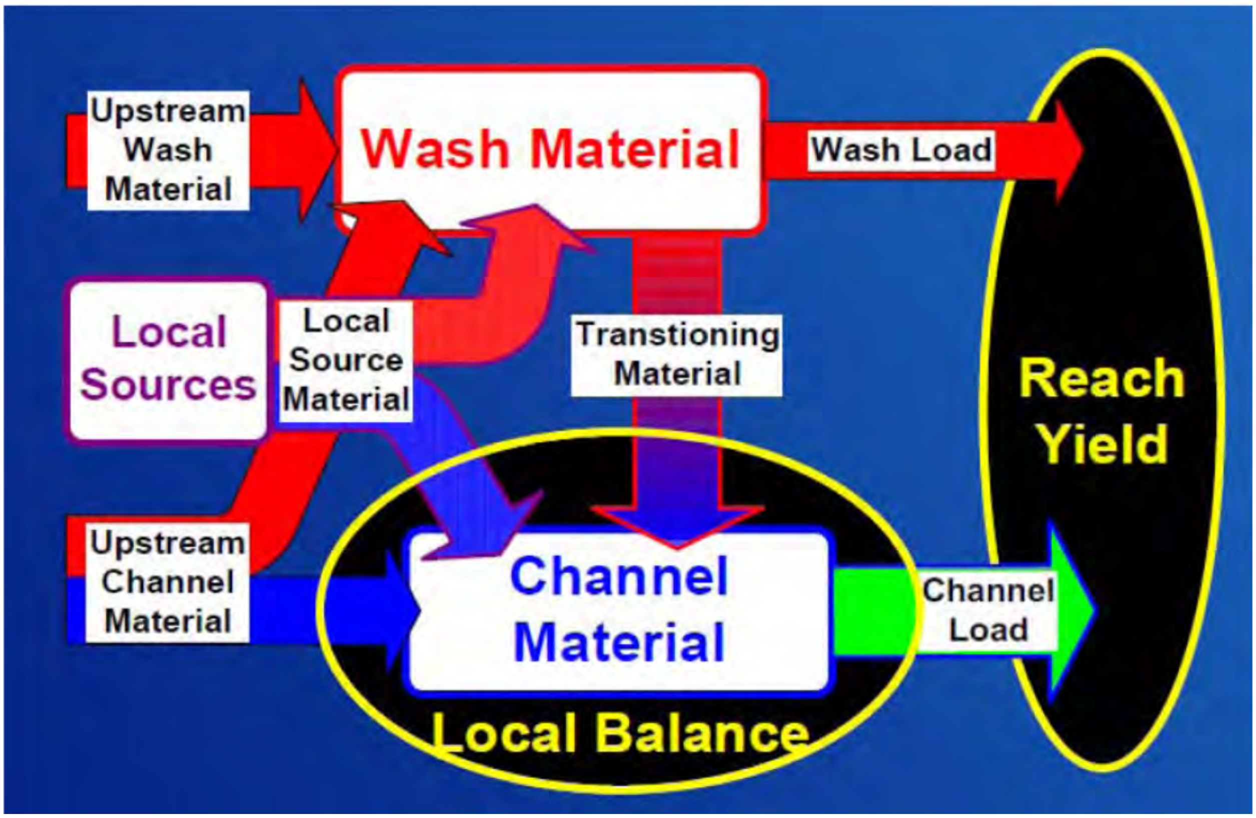


Figure 4-1: SIAM Sediment Balance Schematic (FTER Mooney, 2006)

The SIAM feature was applied for all reaches in Bound brook from just above Belmont Avenue Bridge (RM6.87) to its confluence with Green Brook (RM0) for the following scenarios:

- Base Case - This is the current conditions
- Scenario 1 - Assessment of impact of removing twin culverts on sediment deposition
- Scenario 2 - Assessment the impact of sediment deposition by constructing a dam just upstream of Lakeview Ave between Lakeview Ave and the twin culverts at approximately RM6.2.
- Scenario 3 – Removal of the man-made dam at RM6.0.

4.1. SIAM Sediment Reaches

The first step in SIAM is to subdivide the stream in the HEC-RAS hydraulic model into sediment reaches, which represent the scale at which sediment transport calculations are performed. A sediment reach is defined as a grouping of stream cross-sections with relatively consistent hydraulic and sediment properties, and recognizing any significant geomorphic changes in channel gradient, channel geometry, and sediment composition. Based on these parameters and field observations of sediment texture, Bound Brook was subdivided into fourteen sediment reaches as shown in Figure 4-2. Note that Reach 4 was further subdivided into 4a, 4b and 4c to allow for physical changes to be made for simulation of different restoration/remedial alternatives in SIAM. The river mile boundaries of these reaches are given in Table 4.1.

Table 4.1: Bound Brook SIAM sediment reaches and description of sediment bed gradation

Sediment Reach	River Mile		Bed Gradation
	Upstream Extent	Downstream Extent	
1	6.87	6.64	Mostly sand
2	6.64	6.57	Mostly clay
3*	6.57	6.23[3]	Mostly sand
4a	6.23	6.17	Mostly fine sand
4b**	6.17	6.00[2]	Mostly fine sand
4c	6.00	5.77	Mostly fine sand
5	5.77	5.39	Mostly fine sand
6	5.39	5.04	Mixture of clay silt and sand
7	5.04	4.78	Mostly sand with some silt and clay
8	4.78	4.10	Mostly sand with silt clay mixture
9***	4.10	3.42[1]	Mostly clay and silt with some sand
10	3.42	2.56	Clay, silt sand and some gravel
11	2.56	2.39	Clay, silt sand and some gravel
12	2.39	2.18	Mostly fine to medium sand
13	2.18	1.87	Mostly medium to coarse Gravel

Sediment Reach	River Mile		Bed Gradation
	Upstream Extent	Downstream Extent	
14	1.87	0.00	Mostly fine to medium sand

* Twin culverts are located at approximately RM 6.55 in SIAM Sediment Reach 3
** Manmade dam is located at approximately RM 6.00, which is in SIAM Sediment Reach 4b
*** New Market Pond dam is located at approximately RM3.42, which is in SIAM Sediment Reach 9

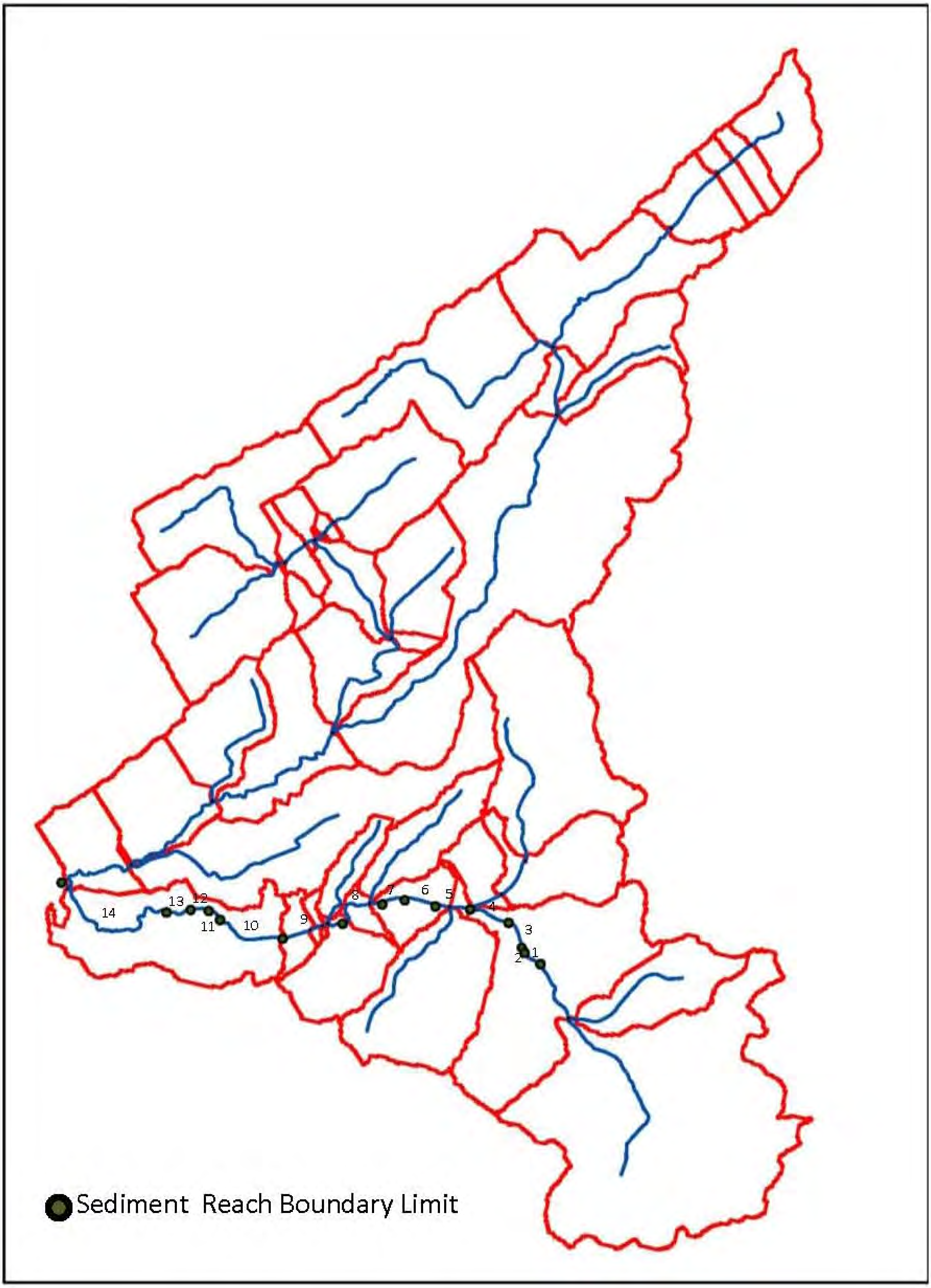


Figure 4.2: Bound Brook SIAM sediment reaches (river miles for each "reach" are provided in Table 4-1)

4.2. SIAM Input Data

The input required for the SIAM module includes cross section data for the study reach, annualized discharge-duration data, bed material gradations, an appropriate sediment transport function, wash load criteria, and annualized sediment input volumes (broken down by grain size fractions). The SIAM modeling was conducted using the calibrated HEC-RAS bank full model that created the elevation-duration curves described in Section 3.

4.2.1. Annualized Discharge Duration

Sediment transport estimates developed by SIAM are based on annualized flow-duration curves created from mean daily discharges. The flow-duration curves used in the SIAM simulations were based on the results of the SWAT simulated stream flow for the period 2005 to 2011 presented in Section 2. For each loading point, the minimum and maximum discharge for the period 2005-2011 was determined, and the resulting range of discharge was divided into 36 bins. There is no guidance on the optimal number of bins to use for the annualized flow-duration curve and review of SIAM applications at other sites indicates that as low as 9 bins to more than 40 bins have been used. The daily discharges simulated by SWAT for each reach were evaluated to determine the number of days that discharge occurred in each bin, and the average annual duration in days was determined for the representative flow of each bin. Table 4.2 shows the discharges simulated at RM0 and corresponding SIAM input duration in days. The total duration must equal 365 days because SIAM predicts annual trends. The discharge at other loading points was analyzed similarly. Each discharge was modeled by in HEC-RAS, and the corresponding average annual days were entered in the SIAM hydro data table for each reach.

Table 4.2: SIAM Flow duration at Downstream Boundary RM0

Discharge (cfs)	Duration (days)	Discharge (cfs)	Duration (days)
7.90	3.44	60.61	7.31
9.53	7.31	74.69	7.31
11.67	7.31	96.09	7.31
14.88	18.21	115.64	3.59
18.03	18.21	127.88	3.73
19.58	18.21	141.47	3.59
21.62	36.57	153.17	3.73
24.35	36.57	166.66	3.59
25.95	18.64	189.86	3.59
26.80	17.93	228.57	3.73
27.39	18.36	266.86	3.59
28.33	18.07	333.37	3.73

Discharge (cfs)	Duration (days)	Discharge (cfs)	Duration (days)
29.30	18.36	400.95	3.59
30.57	18.07	485.91	2.58
35.10	18.36	614.53	1.86
40.10	7.46	821.84	1.43
44.58	10.76	1336.73	1.43
52.07	7.31	4050.59	0.14

4.2.2. Bed Material

Bed material gradations associated with each SIAM sediment reach were determined from low-resolution coring grain size analysis collected during the RI field investigations. For each SIAM sediment reach, the representative grain size distribution was determined based on the predominant sediment texture characteristics reported in the sediment probing field survey during the RI. The bed material gradations used for the SIAM sediment reaches (Figure 4.3) were entered into HEC-RAS as the percent of the total sediment gradation finer than a particular sediment class particle diameter by weight.

4.2.3. Sediment Transport Properties

The sediment transport properties input data for SIAM describe the selected sediment transport function, the particle fall velocity, and the wash load threshold diameter. SIAM includes six different functions to compute sediment transport capacity over a range of bed material sizes, including: Ackers-White, Engelund-Hansen, Laursen-Copeland, Meyer-Peter Müller, Toffaleti, and Yang. The bed material in Bound Brook varies greatly ranging from coarse sand to clay. Of the six available transport functions in SIAM, all but Laursen-Copeland were developed from data based on sand or larger sized particles, making them poor choices for this analysis. The Laursen-Copeland sediment transport function, which was developed for material sizes that extend to the range of coarse silt, finer silts and clay size particles, was selected for all SIAM sediment reaches. Particle fall velocity was set to the default values for the Laursen-Copeland transport function.

The maximum wash load threshold is also required in SIAM. Wash load is defined as sediment in transport and it is generally derived from sources other than the bed (Biedenharn *et. al.*, 2006). SIAM does not apply standard transport equations to compute a mass balance for wash load material (USACE, 2010a,b). Instead, the program automatically passes any particle equal to or smaller than the maximum wash load through the system. Although there is no universally accepted method of selecting a wash load threshold, the material is often considered the fine-sized silt and clay material (particles less than 0.0625 mm in diameter). Einstein (1950) defined wash load as the grain size of which 10 percent of the bed mixture is finer. In this analysis, the wash load threshold diameter was set as 0.004 mm for all reaches.

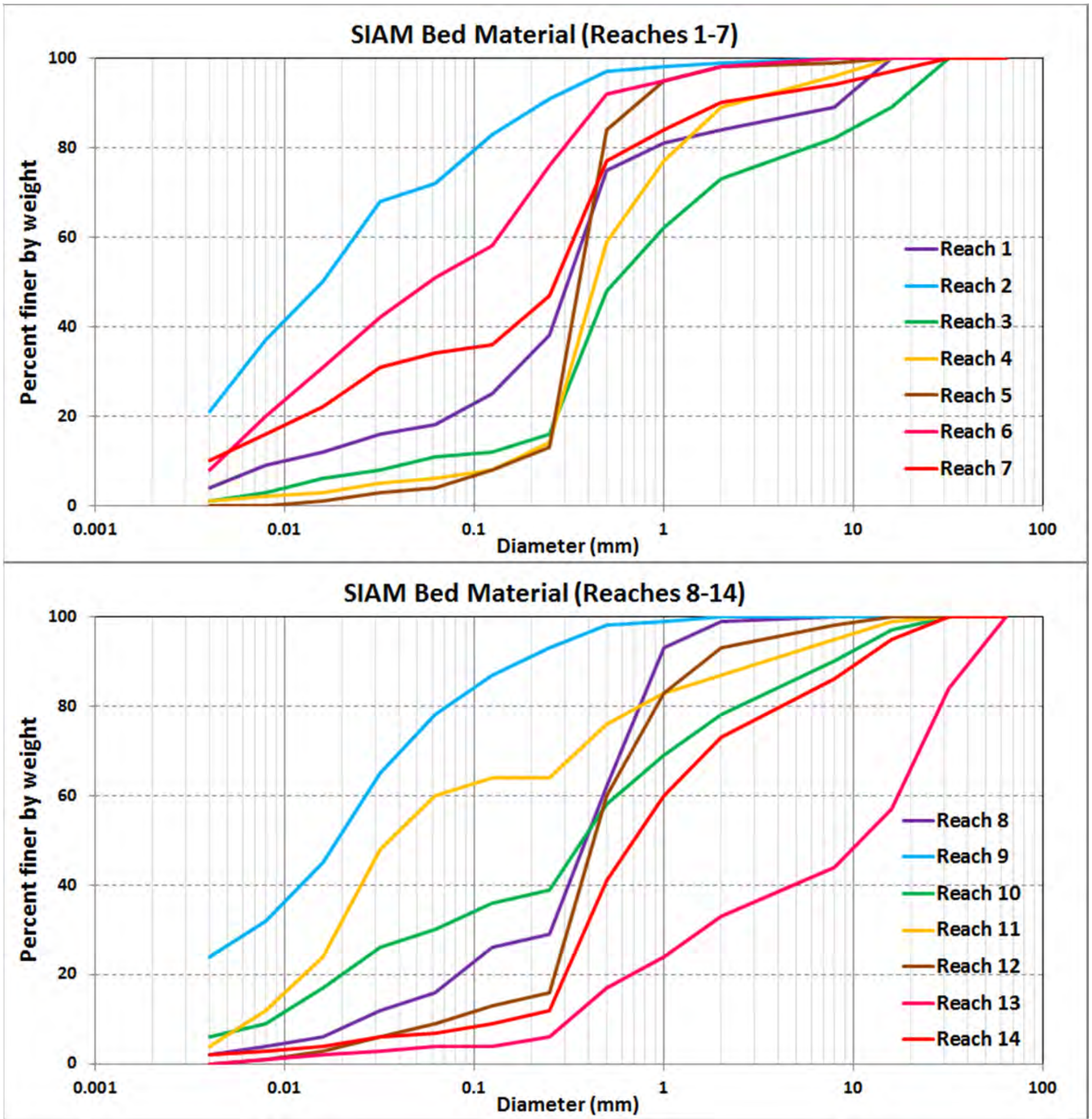


Figure 4.3: Bed Material Gradation for Bound Brook SIAM Sediment Reaches

4.2.4. Sediment Sources

External sediment sources to Bound Brook were based on results of the sediment yield from the watershed SWAT model. SIAM requires sediment supply data to be input for each reach. The sediment supply data are entered by source as annual sediment loads in tons per year per grain class. Two primary sediment sources were identified: channel banks erosion, and upstream or tributary inflows.

Based on field reconnaissance, it was determined that the contribution of bank sediments to the channels due to channel migration occur too slowly to be worth considering as a sediment supply source in the SIAM modeling. Therefore, no estimates of the bank erosion contributions were included in SIAM.

The primary sediment supply for Bound Brook was the contribution from its watershed. During precipitation events, sediments are eroded and subsequently transported to the brook. Based on the results from the watershed sediment yield from the SWAT model (see Section 2), the annual sediment supply to the various reaches are given in Table 4.3. It was assumed that the watershed sediment supply was median silt in texture.

Table 4.3: SIAM Input for Watershed Local Sediment Source

Sediment Reach	River Mile		Local Supply (tons/yr)
	Upstream Extent	Downstream Extent	
1	6.87	6.64	630[1]
2	6.64	6.57	2.1
3[*]	6.57	6.23[3]	9.8
4a	6.23	6.17	2.1
4b[**]	6.17	6.00[2]	5.8
4c	6.00	5.77	7.8
5	5.77	5.39	10
6	5.39	5.04	3.1
7	5.04	4.78	3.1
8	4.78	4.10	28
9[***]	4.10	3.42[1]	32
10	3.42	2.56	12
11	2.56	2.39	2.3
12	2.39	2.18	3.0
13	2.18	1.87	7.8
14	1.87	0.00	44

[1] Upstream Boundary Load
[*] Twin culverts are located at approximately RM 6.55 in SIAM Sediment Reach 3
[**] Manmade dam is located at approximately RM 6.00, which is in SIAM Sediment Reach 4b
[***] New Market Pond dam is located at approximately RM3.42, which is in SIAM Sediment Reach 9

4.2.5. Hydraulics

Hydraulic parameters used in SIAM model calculations were automatically populated from the results of the HEC-RAS simulation. Each discharge specified in the annualized discharge duration profile (see section 4.2.1) corresponds to a flow profile modeled in HEC-RAS. Mean hydraulic values for each profile were determined for each SIAM sediment Reach through a Reach length weighted averaging scheme within HEC-RAS. SIAM uses the reach average values in the sediment transport capacity computations.

4.3. SIAM Results

SIAM is a sediment budget tool that compares annualized sediment transport capacities (i.e., overall sediment surplus or deficit) for each river mile segment, called a "reach." When SIAM simulation is performed, the results of the analysis are presented in different tables and plots with various levels of details. In this study, the model output of interest is a table of sediment supply and balance for each SIAM sediment reach with the following components:

- Local Supply – This represents the source data from SWAT watershed yield that are summarized in Table 4.3 above.
- Transport Capacity – This is the amount of sediment that can be expected to be moved through the reach. It is calculated by determining the hydraulic energy available to transport sediment using the flow-duration curve defined in the input to SIAM (see Table 4.2 above). The hydraulic energy is applied to each available sediment fraction in the bed to determine how much sediment would be available to be transported as a function of grain size. This is called the transport potential of each grain size fraction. The overall transport capacity for the reach is estimated by weighting the transport potential of each grain size as a percentage of what is available in the bed.
- Bed Supply – This is the amount if sediment that can potentially be transported from the next most upstream reach into the current sediment reach. This value is dominated by the transport capacity value from the next upstream reach.
- Wash Supply – This is the sediment loading that is routed through the network as wash load.
- Sum of Local Supplies – This is the sum of local supplies from all upstream reaches.
- The Local Balance is the difference between the transport capacity and the sum of the supplies.

It is worth noting that because SIAM is not a sediment routing model its results represent general trends of surplus and deficit only and not actual volumes of eroded or deposited material. Although SIAM is a very useful sediment management tool, Little and Jonas (2010) indicate that the following limitations should be considered when reviewing the results:

- SIAM does not update the sediment bed based on erosion or deposition (i.e., hydraulics are not updated or changed over time during a model run), and the model does not account for changing capacities in response to potential erosion or deposition.
- No time frame for sediment impacts is computed.

- Reach-averaged values are used in all computations, and therefore, localized effects of hydraulic structures including dams, weirs, and culverts can be overwhelmed by the sediment transport potential estimated for transport capacity.
- There is no supply limitation from the bed in each reach because SIAM assumes erosion will continue indefinitely from the bed until the sediment transport capacity is satisfied. In systems where the local supply from the watershed is limited like in Bound Brook, the sediment transport simulated can be overwhelmed by the transport capacity.

Despite these limitations, SIAM can be used as a screening tool for sediment budget assessment to guide managers in determining areas of potential stability and instability. When scenarios are evaluated, the relative trends estimated by SIAM can help to identify potential restoration priorities and can be the start point for more detailed analysis on the selected restoration option.

4.3.1. Scenario 1: Base Case (Existing Condition)

In this study, the baseline model represents the existing conditions in Bound Brook that were set in SIAM, using inputs from SWAT and HEC-RAS results presented in previous sections of this report. A summary of the reach supply and balance for this scenario is provided in Table 4-4. The model results indicate that there is a deficit (or degradation) in the most upstream SIAM sediment reach (Reach 1). This sediment instability is expected because of boundary condition effects, particularly the relatively small input of sediment from the local watershed in comparison to the transport potential of the reach. The model results indicate that the SIAM sediment reach containing the New Market Pond (Reach 9) has sediment surplus (or aggradation) because of relatively larger potential supply from upstream. Downstream from the New Market Pond, the next three reaches were simulated to have deficit or degradation. It should be noted that the negative local balances in Reaches 6 and 7 are questionable because observed field work in this stretch of the brook suggests that the sediment beds are aggrading and consists of relatively thick beds of fine-grained sediment deposits.

4.3.2. Scenario 2: New Dam Constructed at RM6.2

In this scenario, a dam was placed at RM6.2; it was assumed that the modeled dam had dimensions that were similar in size to the existing New Market Pond dam. The geometry file in HEC-RAS was modified to include this structure. Table 4.5 presents a summary of the SIAM results for this scenario. Implementation of the scenario would result in significant changes upstream of RM6.2 and the modeled dam. Due to the lack of flow upstream of the dam, the energy in the system upstream of the dam is reduced relative to baseline conditions. The transport capacity computed under this scenario for the reaches upstream of the dam (reaches 1 to 4a) are orders of magnitude lower than corresponding values under baseline conditions. Reach 4a which was degrading under baseline conditions, is now simulated to be aggrading under Scenario 2. Model results from reach 4c downstream would not show any changes relative to the baseline scenario.

While the presence of the modeled dam forecasts potential sediment aggradation, it is important to note that there may be flooding implications depending on the dam height. The current simulation assumed a dam height of about 10 feet. If the dam height is increased to 20 feet or more, significant flooding would occur based on results of water elevation from HEC-RAS.

4.3.3. Scenario 3: Removal of Twin Culvert at RM6.55

In this scenario, Bound Brook was modeled assuming that the three existing elliptical reinforced concrete culverts at RM6.55 in SIAM Sediment Reach 3, which is adjacent to the CDE site, were removed from the Brook. Two of these culverts are twin culverts and each having dimensions of approximately 7.5 feet high and 7.0 feet in width. The third culvert, which is separated from the twin culverts (see Figure 4.4) is approximately 5.8 feet high and spans 5.5 feet. The geometry file in HEC-RAS was modified to exclude the structures. Table 4.6 presents a summary of the reach supply and balance for this scenario.

Figure 4.4: Existing Culverts at River Mile 6.55

The SIAM results of this scenario show slightly more sediment aggradation relative to baseline conditions, in the sediment reach upstream of the project upper limit (Reach 1), since the removal of the twin culverts might slightly increase the velocity and energy in that area. The reaches containing the twin culverts show increased aggradation relative to baseline conditions. No changes were simulated for Scenario 3 relative to baseline conditions downstream of Reach 5.

4.3.4. Scenario 4: Removal of Manmade Dam at RM6.0

In this scenario, Bound Brook was modeled assuming that the existing manmade dam at the end of SIAM sediment reach 4b (RM6.0) was removed. Table 4.7 presents a summary of the reach supply and balance for this scenario. The model results show that removal of the dam creates additional sediment deficit in the reach just upstream relative to baseline conditions. This deficit from the reach just upstream results in the supply of sediments to reach 4b creating a surplus after the dam is removed.

Table 4-4. SIAM Reach Supply and Balance for the Baseline Model (Existing Condition)

SIAM Sediment Reach	River Mile		Local Supply (tons/yr)	Transport Capacity (tons/yr)	Bed Supply (tons/yr)	Wash Supply (tons/yr)	Sum Local Supplies (tons/yr)	Local Balance (tons/yr)
	From	To						
Reach 1	6.87	6.64	628	4.55E+06	597	31.4	628	-4.55E+06
Reach 2	6.64	6.57	2.08	2.48E+05	4.55E+06	31.5	630	4.30E+06
Reach 3*	6.57	6.23	9.81	3.99E+06	2.48E+05	32	640	-3.74E+06
Reach 4a	6.23	6.17	2.04	4.26E+06	3.99E+06	32.1	642	-2.69E+05
Reach 4b**	6.17	6.00	5.79	5.49E+07	4.26E+06	32.4	648	-5.07E+07
Reach 4c	6.00	5.77	7.83	1.02E+05	5.49E+07	32.7	655	5.48E+07
Reach 5	5.77	5.39	10.4	3.04E+04	1.02E+05	33.3	666	7.20E+04
Reach 6	5.39	5.04	3.09	2.56E+06	3.04E+04	33.4	669	-2.53E+06
Reach 7	5.04	4.78	3.07	5.86E+06	2.56E+06	33.6	672	-3.31E+06
Reach 8	4.78	4.10	27.7	2.82E+05	5.86E+06	35	700	5.58E+06
Reach 9***	4.10	3.42	32.4	5.79E+04	2.82E+05	36.6	732	2.24E+05
Reach 10	3.42	2.56	12	4.03E+06	5.79E+04	37.2	744	-3.97E+06
Reach 11	2.56	2.39	2.25	5.43E+07	4.03E+06	37.3	746	-5.03E+07
Reach 12	2.39	2.18	2.99	1.89E+08	5.43E+07	37.4	749	-1.35E+08
Reach 13	2.18	1.87	7.84	5.14E+07	1.89E+08	37.8	757	1.38E+08
Reach 14	1.87	0.00	43.8	3.81E+06	5.14E+07	40	801	4.76E+07

* Twin culverts are located at approximately RM 6.55 in SIAM Sediment Reach 3
** Manmade dam is located at approximately RM 6.00, which is in SIAM Sediment Reach 4b
*** New Market Pond dam is located at approximately RM3.42, which is in SIAM Sediment Reach 9

Note: The negative local balances in Reaches 6 and 7 are questionable because observed field work in this stretch of the brook suggests that the sediment beds are aggrading and consists of relatively thick beds of fine-grained sediment deposits.

Table 4-5. SIAM Reach Supply and Balance for the Scenario 2 - New Dam Constructed at RM6.2

SIAM Sediment Reach	River Mile		Local Supply (tons/yr)	Transport Capacity (tons/yr)	Bed Supply (tons/yr)	Wash Supply (tons/yr)	Sum Local Supplies (tons/yr)	Local Balance (tons/yr)
	From	To						
Reach 1	6.87	6.64	628	6328	597	31.4	628	-5.73E+03
Reach 2	6.64	6.57	2.08	13.6	6330	31.5	630	6.32E+03
Reach 3*	6.57	6.23	9.81	9047	22.9	32	640	-9.02E+03
Reach 4a	6.23	6.17	2.04	4507	9049	32.1	642	4.54E+03
Reach 4b**	6.17	6.00	5.79	5.49E+07	4512	32.4	648	-5.49E+07
Reach 4c	6.00	5.77	7.83	1.02E+05	5.49E+07	32.7	655	5.48E+07
Reach 5	5.77	5.39	10.4	3.04E+04	1.02E+05	33.3	666	7.20E+04
Reach 6	5.39	5.04	3.09	2.56E+06	3.04E+04	33.4	669	-2.53E+06
Reach 7	5.04	4.78	3.07	5.86E+06	2.56E+06	33.6	672	-3.31E+06
Reach 8	4.78	4.10	27.7	2.82E+05	5.86E+06	35	700	5.58E+06
Reach 9***	4.10	3.42	32.4	5.79E+04	2.82E+05	36.6	732	2.24E+05
Reach 10	3.42	2.56	12	4.03E+06	5.79E+04	37.2	744	-3.97E+06
Reach 11	2.56	2.39	2.25	5.43E+07	4.03E+06	37.3	746	-5.03E+07
Reach 12	2.39	2.18	2.99	1.89E+08	5.43E+07	37.4	749	-1.35E+08
Reach 13	2.18	1.87	7.84	5.14E+07	1.89E+08	37.8	757	1.38E+08
Reach 14	1.87	0.00	43.8	3.81E+06	5.14E+07	40	801	4.76E+07

[*] Twin culverts are located at approximately RM 6.55 in SIAM Sediment Reach 3
[**] Manmade dam is located at approximately RM 6.00, which is in SIAM Sediment Reach 4b
[***] New Market Pond dam is located at approximately RM3.42, which is in SIAM Sediment Reach 9

Note: The negative local balances in Reaches 6 and 7 are questionable because observed field work in this stretch of the brook suggests that the sediment beds are aggrading and consists of relatively thick beds of fine-grained sediment deposits.

Table 4-6. SIAM Reach Supply and Balance for the Scenario 3 - Removal of Twin Culverts at RM6.55

SIAM Sediment Reach	River Mile		Local Supply (tons/yr)	Transport Capacity (tons/yr)	Bed Supply (tons/yr)	Wash Supply (tons/yr)	Sum Local Supplies (tons/yr)	Local Balance (tons/yr)
	From	To						
Reach 1	6.87	6.64	628	4.78E+06	597	31.4	628	-4.78E+06
Reach 2	6.64	6.57	2.08	3.03E+05	4.78E+06	31.5	630	4.48E+06
Reach 3*	6.57	6.23	9.81	3.67E+06	3.03E+05	32	640	-3.37E+06
Reach 4a	6.23	6.17	2.04	4.25E+06	3.67E+06	32.1	642	-5.80E+05
Reach 4b**	6.17	6.00	5.79	5.49E+07	4.25E+06	32.4	648	-5.07E+07
Reach 4c	6.00	5.77	7.83	1.02E+05	5.49E+07	32.7	655	5.48E+07
Reach 5	5.77	5.39	10.4	3.04E+04	1.02E+05	33.3	666	7.20E+04
Reach 6	5.39	5.04	3.09	2.56E+06	3.04E+04	33.4	669	-2.53E+06
Reach 7	5.04	4.78	3.07	5.86E+06	2.56E+06	33.6	672	-3.31E+06
Reach 8	4.78	4.10	27.7	2.82E+05	5.86E+06	35	700	5.58E+06
Reach 9***	4.10	3.42	32.4	5.79E+04	2.82E+05	36.6	732	2.24E+05
Reach 10	3.42	2.56	12	4.03E+06	5.79E+04	37.2	744	-3.97E+06
Reach 11	2.56	2.39	2.25	5.43E+07	4.03E+06	37.3	746	-5.03E+07
Reach 12	2.39	2.18	2.99	1.89E+08	5.43E+07	37.4	749	-1.35E+08
Reach 13	2.18	1.87	7.84	5.14E+07	1.89E+08	37.8	757	1.38E+08
Reach 14	1.87	0.00	43.8	3.81E+06	5.14E+07	40	801	4.76E+07

* Twin culverts are located at approximately RM 6.55 in SIAM Sediment Reach 3
** Manmade dam is located at approximately RM 6.00, which is in SIAM Sediment Reach 4b
*** New Market Pond dam is located at approximately RM3.42, which is in SIAM Sediment Reach 9

Note: The negative local balances in Reaches 6 and 7 are questionable because observed field work in this stretch of the brook suggests that the sediment beds are aggrading and consists of relatively thick beds of fine-grained sediment deposits.

Table 4-7. SIAM Reach Supply and Balance for the Scenario 4 - Removal of Manmade Dam at RM6.00

SIAM Sediment Reach	River Mile		Local Supply (tons/yr)	Transport Capacity (tons/yr)	Bed Supply (tons/yr)	Wash Supply (tons/yr)	Sum Local Supplies (tons/yr)	Local Balance (tons/yr)
	From	To						
Reach 1	6.87	6.64	628	4.55E+06	597	31.4	628	-4.55E+06
Reach 2	6.64	6.57	2.08	2.48E+05	4.55E+06	31.5	630	4.30E+06
Reach 3*	6.57	6.23	9.81	3.99E+06	2.48E+05	32	640	-3.74E+06
Reach 4a	6.23	6.17	2.04	6.65E+06	3.99E+06	32.1	642	-2.66E+06
Reach 4b**	6.17	6.00	5.79	2.57E+06	6.65E+06	32.4	648	4.08E+06
Reach 4c	6.00	5.77	7.83	1.02E+05	2.57E+06	32.7	655	2.47E+06
Reach 5	5.77	5.39	10.4	3.04E+04	1.02E+05	33.3	666	7.20E+04
Reach 6	5.39	5.04	3.09	2.56E+06	3.04E+04	33.4	669	-2.53E+06
Reach 7	5.04	4.78	3.07	5.86E+06	2.56E+06	33.6	672	-3.31E+06
Reach 8	4.78	4.10	27.7	2.82E+05	5.86E+06	35	700	5.58E+06
Reach 9***	4.10	3.42	32.4	5.79E+04	2.82E+05	36.6	732	2.24E+05
Reach 10	3.42	2.56	12	4.03E+06	5.79E+04	37.2	744	-3.97E+06
Reach 11	2.56	2.39	2.25	5.43E+07	4.03E+06	37.3	746	-5.03E+07
Reach 12	2.39	2.18	2.99	1.89E+08	5.43E+07	37.4	749	-1.35E+08
Reach 13	2.18	1.87	7.84	5.14E+07	1.89E+08	37.8	757	1.38E+08
Reach 14	1.87	0.00	43.8	3.81E+06	5.14E+07	40	801	4.76E+07

* Twin culverts are located at approximately RM 6.55 in SIAM Sediment Reach 3
** Manmade dam is located at approximately RM 6.00, which is in SIAM Sediment Reach 4b
*** New Market Pond dam is located at approximately RM3.42, which is in SIAM Sediment Reach 9

Note: The negative local balances in Reaches 6 and 7 are questionable because observed field work in this stretch of the brook suggests that the sediment beds are aggrading and consists of relatively thick beds of fine-grained sediment deposits.

5. Summary

A combination of field measurements, watershed hydrologic modeling, hydraulics and sediment transport modeling was used to develop a reach by reach sediment impact analysis for Bound Brook. This analysis is one of the tools used to evaluate potential remediation scenarios for the Bound Brook feasibility study.

The watershed hydrologic and stream hydraulics models were required to provide the necessary inputs for the sediment transport model. The watershed model SWAT was used to simulate stream flows and sediment yields in Bound Brook. Stream flow data available at the USGS stream gauge at Middlesex, New Jersey (Gauge ID: 01403900) were used for calibration and validation of the model simulated flows. In addition, a sediment load rating curve was developed using measured suspended solids concentrations at this gauge. The sediment yield derived from this rating curve was compared to the simulated sediment yield generated by SWAT. Overall, the watershed model was successfully calibrated and validated using the measured flows. The simulated sediment yield also agreed to the sediment yields that were derived from suspended solids concentrations and flow measurements. The sub-watershed delivery of flow and solids were used as input to HEC-RAS and SIAM models.

For in-stream hydraulics modeling, the one-dimensional model HEC-RAS was used to represent the brook. This model provided a reliable method for calculating hydraulic conditions, including water surface elevation, flow depth, and velocity over a range of flows provided by the SWAT model. Channel stream geometry was based on a combination of elevation surveys and USGS National Elevation Dataset digital elevation models. Significant structures like bridges, dams and culverts were fully represented in the model's geometry. Roughness was used as the calibrating parameter, but this parameter was varied within ranges that are based on field observations of debris in stream, vegetation, channel irregularities, degree of meander, obstructions, size and shape of the channel. A comparison of simulated water surface elevations at several points along the brook indicated good agreement to actual elevations measured during the field program.

The sediment assessment model (constructed using SIAM feature in HEC-RAS) was used to evaluate potential changes in sedimentation patterns that could occur due to remedial alternatives assessed as part of the feasibility study. Although SIAM is not a sediment transport model, it was used to compare the annual sediment transport capacity of a stream "reach" (or river mile segment) to the sediment supply, and the model provides an indication of whether sediment aggradation, degradation, or equilibrium may occur.

Under existing conditions, the model produced reliable results with aggradation in the "reach" above New Market Pond dam and degradation below the dam, which is consistent with field observations. For the remedial scenarios evaluated by the model, construction of a new dam at RM6.2 was simulated to produce back-up of water in the reaches above this point. The model suggests that sediment aggradation would occur due to the construction of the new dam. SIAM shows slight changes in supply and deficit of sediments as a result of removing either the twin culverts at RM6.55, and manmade dam at RM6.0. It is recommended that future sensitivity analyses be conducted to understand the uncertainties in the SIAM model results and the significance of some of the parameters used in SIAM (such as wash load, sediment bed gradation, and the specification of sediment reaches).

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